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## The Effect of Different Kinds of Stormwater Quality Improvement Devices on Stormwater Quality within the Sutherland Shire

Thomas H. Cook

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# The Effect of Different Kinds of Stormwater Quality Improvement Devices on Stormwater Quality within the Sutherland Shire

## Abstract

Waterways represent an important part of the urban landscape due to the potential human and ecological health impacts associated with them. As a result of this, considerable effort is invested in the improvement and protection of urban stream water quality. This study examined the treatment efficiency of six stormwater quality improvement devices (SQIDs) located across the Sutherland Shire. A range of water quality indicators were assessed and the concentrations of these constituents were measured at both the inflow and the outflow, to determine the relative differences between these two points. These data were compared with established guidelines for stormwater quality, namely the Australian Runoff Quality Guidelines by Wong (2006), to provide an indication of pollution in the catchment and the operational efficiency of the SQIDs. Rainfall data and land use zoning maps were used to identify potential sources of pollution in the catchment and explain the pattern of constituent concentrations detected. It was found that four of the six sites examined were functioning relatively well and were achieving adequate reductions in the pollutant loads arising at the inflow. While the results of this study did not clearly demonstrate which treatment device design was superior, it showed that it is necessary to specifically construct installations for stormwater treatment, if they are to be successful. Modifying existing infrastructure, originally designed for other purposes, is inadequate, as illustrated by the two poorly functioning systems identified in this report. By investigating urban water quality and SQID operation, decision makers can become better informed, thereby improving stormwater and urban catchment management in the future.

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THE EFFECT OF DIFFERENT KINDS OF  
STORMWATER QUALITY IMPROVEMENT DEVICES  
ON STORMWATER QUALITY WITHIN  
THE SUTHERLAND SHIRE

By

THOMAS H. COOK

A research report submitted in partial fulfilment of the  
requirements for the award of the degree of

HONOURS BACHELOR OF ENVIRONMENTAL SCIENCE

ENVIRONMENTAL SCIENCE PROGRAM  
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## **Abstract**

Waterways represent an important part of the urban landscape due to the potential human and ecological health impacts associated with them. As a result of this, considerable effort is invested in the improvement and protection of urban stream water quality. This study examined the treatment efficiency of six stormwater quality improvement devices (SQIDs) located across the Sutherland Shire. A range of water quality indicators were assessed and the concentrations of these constituents were measured at both the inflow and the outflow, to determine the relative differences between these two points. These data were compared with established guidelines for stormwater quality, namely the Australian Runoff Quality Guidelines by Wong (2006), to provide an indication of pollution in the catchment and the operational efficiency of the SQIDs. Rainfall data and land use zoning maps were used to identify potential sources of pollution in the catchment and explain the pattern of constituent concentrations detected. It was found that four of the six sites examined were functioning relatively well and were achieving adequate reductions in the pollutant loads arising at the inflow. While the results of this study did not clearly demonstrate which treatment device design was superior, it showed that it is necessary to specifically construct installations for stormwater treatment, if they are to be successful. Modifying existing infrastructure, originally designed for other purposes, is inadequate, as illustrated by the two poorly functioning systems identified in this report. By investigating urban water quality and SQID operation, decision makers can become better informed, thereby improving stormwater and urban catchment management in the future.

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## **1. Introduction**

Waterways are an important community asset, involved in the maintenance of drinking water supplies, the natural environment and as places of recreational value and aesthetic beauty. The role they play in determining the health of ocean ecosystems and, therefore, the success of industries dependent upon the marine environment, further demonstrates their importance to human society and quality of life. Despite the obvious importance of these systems, many waterways are under continual stress due to human influences on waterways and the catchments which supply them. These impacts are particularly apparent in urban waterways where substantial redevelopment of the catchment environment and of the channel geometry can be responsible for a range of problems. Pollution of such waterways by a plethora of different substances represents one of the central issues affecting urban streams and rivers.

### **1.1 Pollution in Urban Waterways**

Following the approach of Wong (2006), pollutants can be broadly categorised under four main headings, these being, toxicants, physical and chemical stressors, microbial pathogens and gross contaminants. Toxicants include a number of heavy metals such as chromium, cadmium, nickel, lead, copper and zinc as well as ammonia, oil and petroleum hydrocarbons and pesticides, fungicides and herbicides. The role hardness, alkalinity and salinity play in determining the toxicity of heavy metals in aquatic environments is generally constant, with toxicity decreasing as these parameters increase (Wong, 2006). Chromium and cadmium are derived from similar sources such as the metal industry, domestic products, pesticides, fertilizers and vehicles with cadmium being found in tyres and brake pads and chromium found in engine parts (Wong, 2006). Dissolved organic matter can reduce toxicity due to cadmium being readily adsorbed by suspended material. Cadmium's bioaccumulation potential is variable but can have significant implications for bivalves in marine and estuarine environments (Wong, 2006). Chromium generally exists in two different forms, chromium (III) and chromium (VI), and the relevant concentrations of each determine the toxicity to aquatic organisms. Chromium (VI) for instance, is more toxic at low pH and is also known to bioaccumulate to a certain extent, while Chromium (III) can bioaccumulate in suspended solids (Wong, 2006). Copper, nickel and zinc are all found at low background concentrations

in most natural waters and are essential trace elements required by many aquatic organisms, although toxicity can be a problem at higher concentrations (Fu and Wang, 2011). Copper is derived from the same kinds of anthropogenic sources as cadmium including the wear of vehicle tyres and brake pads, as well as copper pipes, and is capable of accumulating within organisms (Sorme and Lagerkvist, 2002). Sources of nickel in the urban environment include the metal industry, domestic products and engine parts. Thankfully the bioavailability of nickel is dramatically reduced when it is adsorbed onto suspended particulate matter and bioaccumulation of nickel is not a concern (Wong, 2006). Zinc enters urban waterways from the corrosion of metal objects, and the wearing of vehicle tyres and brakes (Sorme and Lagerkvist, 2002). Zinc toxicity decreases as pH falls below 8. Dissolved organic matter is important for the removal of zinc toxicity as zinc forms complexes with this material (Wong, 2006). Lead is sourced from petrol and paint additives and industrial and wastewater discharges (Gray and Becker, 2002). The toxicity of lead will increase as the pH falls below 6 and it will bioaccumulate in aquatic organisms, although in most cases it is not available in large enough quantities to cause any issues (Wong, 2006).

Ammonia represents a non-metal toxicant and is a key form of total nitrogen in the aquatic environment; it will therefore occur naturally, albeit at low levels (Wong, 2006). The proportion of nitrogen present as ammonia can be significantly affected by anthropogenic influences such as industrial processes (Cutrofello and Durant, 2007) and the addition of organic material and nutrients, human and animal wastes and fertilisers to the system (Gray and Becker, 2002). High additions of nitrogen to an aquatic environment can cause an increase in ammonia levels due to the reduction of nitrate to ammonia. Ammonia is a nutrient and can therefore promote the growth of nuisance species such as blue-green algae which can lead to a decrease in carbon dioxide concentrations and an increase in pH (Cutrofello and Durant, 2007). Oil and petroleum hydrocarbons are another example of a non-metal toxicant and can enter waterways by a number of means such as, leaking fuel storage tanks (Wong, 2006), petroleum refinery wastewater and other urban and industrial sources (Saito et al., 2010). One major effect of these kinds of pollutants is shoreline smothering, which can affect the pneumatophores of mangroves for example, as well as toxicity effects (Proffitt et al., 1995). Oil is biodegradable and over time will undergo a natural process of removal from the environment. Pesticides, fungicides and herbicides can include a wide variety of chemicals capable of initiating a range of effects in insects, birds, fish and mammals by inhibiting key enzymes (Wong, 2006). Their presence in urban waterways is therefore something of concern.

Physical and chemical stressors can include nuisance plant growth stimulants, oxygen demanding substances and suspended particulate material (Wong, 2006). Phosphorus, nitrogen and carbon are the central nutrients responsible for promoting plant growth. Typically, urban catchments are responsible for contributing the highest nutrient loads to waterways and this can result in elevated quantities of phosphorus and nitrogen entering the system (Roberts et al., 2009). High nutrient levels in waterways can cause increased growth of aquatic plants and cause problems such as algal blooms (Chen et al., 2008). Algal blooms can outcompete other aquatic plant species by way of light competition and often release toxins into the environment which can damage fishing industries and close beaches. The impact high nutrient levels are likely to have depends upon a number of factors, such as temperature, water body hydraulic detention time and light availability, making it difficult to predict at what point the levels will become adverse (Wong, 2006). Strict monitoring is therefore needed to continually assess the situation. Oxygen demanding substances are usually associated with the natural process of waterway plant production and decomposition (Wong, 2006). When this process is disrupted, through an increase in plant production for example, the natural supply and demand for oxygen within the ecosystem can be stressed. Low dissolved oxygen levels can be responsible for a number of problems including impaired fish development and fish and macroinvertebrate habitat degradation through the desorption of phosphorus and metals from the sediment (Boeder and Chang, 2008). Suspended particulate material is a natural feature of all urban waterways with material derived from soils and growth and decomposition of plant matter (Wong, 2006). Urban catchments can deliver increased quantities of such material, however, through erosion and runoff from streets and buildings. Construction sites for example can deliver significant amounts of inorganic soil particles (Kalainesan et al., 2009) which are of a concern due to the diversity of contaminants incorporated within such particles (Bilotta and Brazier, 2008). Increases in suspended material can be responsible for reducing light penetration to aquatic plants as well as smothering organisms and causing mechanical abrasion of the gills of fish and other species (Wong, 2006). Furthermore, the deposition of contaminated sediments can result in the later release of toxic substances.

The third category of pollutants according to Wong (2006), microbial pathogens, can come from both natural and anthropogenic sources. For instance, animal faeces and sewer overflows are two of the main sources of such contamination. This can result in contamination

by faecal coliforms such as *Enterococci*, which is a good indicator of overall faecal pollution. Although the impacts of such pollution on the environment are limited, the danger to human health can be substantial with these kinds of pathogens responsible for causing a wide range of diseases (Lavender and Kinzelman, 2009).

Wong's (2006) fourth category, gross contaminants, is a term used to encompass the variety of larger solids which may enter an urban waterway such as litter, vegetation and coarse sediment. This forms the most visible portion of waterway pollution and is often what encourages residents to take action to ensure the health of their local streams and rivers. Gross pollutants have an aesthetic impact but can also cause contamination through the supply of oxygen demanding material or metals (Allison et al., 1997). They can also be ingested by aquatic organisms, mistaking them as food, and cause the smothering of aquatic habitats.

## **1.2 Stormwater Quality Improvement Devices**

The diversity of pollutants found within urban waterways makes the management of these contaminants a complicated process, whereby one approach cannot be used to address all the problems likely to be encountered. The relative size of pollutants is one such defining factor which controls the mitigation methods employed. Gross pollutants are a commonly targeted pollution type, the control of which is addressed through the installation of gross pollutant traps (GPTs); (Wong, 2006). There is a diverse array of GPTs available, which according to the South Australian Department of Planning and Local Government (SADPLG); (2010), can be divided into five main categories, these being, drainage entrance treatments, direct screening devices, non-clogging screens, floating traps and sediment traps. Drainage entrance treatments are generally used for smaller catchments or in situations where the receiving water environment is close to the catchment. They operate by capturing pollutants at the entrance points to the stormwater system either through restricting the entrance size, capturing the pollutants as stormwater flows into the system or collecting the pollutants in the entrance pit (Wong, 2006). Examples include side entry pit traps, return flow litter baskets and channel nets. Channel nets are free draining mesh bags used to collect the pollutants and allow the water to flow through them into the drainage pit (SADPLG, 2010). The bags can then be emptied either manually or with a vacuum system. The advantages of such a system are that high pollution areas can be targeted by locating the drainage entrance treatments close to the pollutant source and they can reduce downstream pipe blockages (Wong, 2006).



Unfortunately, the depth of existing drain entrances limits their installation in some areas and maintenance can be time consuming due to the large numbers that may be need to be installed in an area.

The second type, direct screening devices, involves the installation of litter collection baskets, trash racks and channel nets perpendicular to the direction of flow (SADPLG, 2010). The pollutants accumulate behind the barrier, preventing their continued passage down the channel. This form of GPT is generally used for catchment areas between 5 and 200 hectares. While it is common for these devices to be installed within the channel itself some may be located adjacent to the drainage system and water diverted into them via a diversion weir (SADPLG, 2010). There are many different weir designs including solid walls, slotted pipes or staggered vanes. The benefit of this approach is that during flooding the weir is bypassed, preventing damage to the screening device. Some direct screening devices such as trash racks and those with diversion weirs are also capable of collecting considerable quantities of coarse sediment which settles out as a result of the flow being slowed as it passes the obstruction (Allison et al., 1997). Direct screening devices can be installed above or below ground which provides flexibility in their installation. Underground systems can be located in highly developed urban areas with minimal visual impact and can be used to collect bed load sediment (Wong, 2006). Above ground designs enable the simple monitoring of collection rates as well as promoting easy cleaning. Another benefit is the storage of pollutants in a free draining environment. Underground storage occurs in wet sumps where the pollutants may be transformed into more bio-available forms thus creating further complications. Effective maintenance of direct screening devices involves removing collected material from screens and sumps and cleaning the screens which is vitally important to the continued function of a direct screening device. Dirty screens are likely to clog which reduces their operational efficiency during the next storm event (Wong, 2006).

The third group of GPTs are designed to address the problem of screen clogging which can limit the effectiveness of direct screening devices (SADPLG, 2010). There are two types of non-clogging screens available, the first being a circular screen and the second a downwardly inclined screen. Generally, circular screens are used in underground systems and downwardly inclined screens are used in above ground devices. Circular screens for example, are used in a continuous deflective separation (CDS), where the solids are kept in continuous motion to prevent them blocking the screen (Allison et al., 1997). In a downwardly inclined

screen the solids are encourage to move along the screen therefore leaving the top free for water to pass (Wong, 2006). Essentially all other design principles are the same as conventional direct screening devices and they are maintained in much the same way. The major difference and benefit of the non-clogging design is that it can continue to filter flows for the duration of a storm event and therefore treat a greater runoff volume (Wong, 2006)

The fourth category of GPTs, floating traps, are traditionally used in the lower sections of a waterway, where flow velocities are lowest, as a method of capturing highly buoyant and visible pollutants (SADPLG, 2010). They are typically characterised by flexible floating booms installed across a waterway in order to collect material behind them, however newer designs are also fitted with skirts to direct pollutants into storage compartments (Allison et al., 1997). The benefits of this kind of device are that they are highly portable and can be easily installed and repositioned as required (Wong, 2006). Monitoring of pollutant collection is also simple due to their high visibility. This high visibility is something which can be exploited to promote issues of water quality and educating the public around preventing pollution of waterways. Unfortunately these devices are only limited to locations of low flow and during high flow periods much of the pollutants are able to escape. Maintenance can also be expensive and time consuming due to the need for boat access although some smaller devices can be cleaned using vacuum equipment (SADPLG, 2010).

The final category of GPTs, known as sediment traps, can take many different forms and levels of complexity. For example they may range from an earth or concrete basin to advanced structures using vortices and secondary flows for sediment retention (SADPLG, 2010). Examples of such systems include sediment settling basins, ponds, circular settling tanks and hydrodynamic separators. Two main processes can be employed to achieve sediment removal, these being, fine screening or secondary flow motions and simple sedimentation processes (Wong, 2006). The fine screening or secondary flow approach may employ the use of direct screening devices or non-clogging screens. Sediment settling basins operate by rapidly enlarging the channel to achieve a reduction in flow velocity and subsequent settling of the sediment to the bottom. Another benefit of such installations is the potential to create an artificial wetland where riparian vegetation, growing within the basin, can be involved in consuming nitrogen and phosphorus found in the water as well as controlling the microbiological quality of the water (Ghermandi et al., 2009). It is therefore quite common to install one or more of the GPT devices discussed above, in conjunction with

a wetland type system to achieve a more comprehensive treatment of the stormwater. In these instances, the system as a whole can generally be referred to as a Stormwater Quality Improvement Device (SQID), a term which has been utilised for the purposes of this study. Wetland systems are maintained by removing the accumulated sediment and harvesting vegetation when required, which can involve substantial disturbance to an area. As a result of this the maintenance regime of such basins generally operates on a 1 to 5 year cycle depending on the nature of the catchment (Wong, 2006).

### **1.3 Water Quality Monitoring**

Although the quality of GPTs is improving and their operational efficiency is increasing, effective stormwater management cannot simply be addressed through the installation of a series of SQIDs across a catchment's major river systems. Responsible stormwater management requires the implementation of a comprehensive water quality analysis program to actively monitor the health of the water flowing from the catchment. Such water quality monitoring has particular relevance to catchment use planning which can guide decisions that could eventually determine the health of the waterway in the future. Urbanisation, for example, is characterised by multiple land use changes such as removal of vegetation, drainage channel modifications and increases in the impervious surface area (Goonetilleke et al., 2005). The combined impact of these changes ultimately causes a change in the hydrologic regime of the catchment causing increased runoff and reductions in the time to runoff peak. As a result, it is emphasised by Goonetilleke et al. (2005), that recognition of the impact urbanisation has upon the water environment is central to effective urban resource planning and management. In addition to disruption of the hydrological regime, urbanisation can impact upon water quality as a consequence of the physical, chemical and biological pollutants commonly produced during anthropogenic activities (Goonetilleke et al., 2005). As stated by Goonetilleke et al. (2005), stormwater runoff is recognised as the primary transport mechanism responsible for directing non-point source pollution into urban waterways. This realisation highlights the importance of managing stormwater to prevent the entry of pollutants into local waterways and the importance of conducting water quality testing to understand the nature of the pollutant loads which are entering the system. This can lead to the more informed placement of stormwater quality improvement devices and a better understanding of the relative impacts of different catchment land use types on the surrounding waterways. Interestingly, it is advocated by Shrestha et al. (2008), that it is more important to

effective water quality management to assess changes in the concentrations of targeted parameters rather than the actual concentrations, thus highlighting the need for repetitive sampling over time.

The importance of operating a comprehensive water quality monitoring programme, as discussed above, demands the need to test for a variety of water quality parameters in order to give an accurate representation of the health of a waterway. It is intended that these parameters will provide an assessment of the concentrations and potential impacts of the four main pollutants provided by Wong (2006), these being, toxicants, physical and chemical stressors, microbial pathogens and gross contaminants. Gross contaminants are generally assessed by way of a visual inspection along with weighing and counting the collected debris (Allison et al., 1997). This provides the opportunity to report on the pollutant load by both mass and frequency as achieved by Allison et al. (1997). Standard water quality parameters such as pH, electrical conductivity (EC), dissolved oxygen (DO), alkalinity and temperature (Nedeau et al., 2003) can give an initial indication about the effect of the different pollutants listed above. DO, which is impacted by water temperature and salinity, can be used as a basic indicator for aquatic stress (Taner et al., 2011) and the presence of physical and chemical stressors, due to its influence on water chemistry, as discussed by Wong (2006). These parameters are often measured in the field using portable devices, as in the study by Taner et al. (2011), where DO, pH, EC and salinity, were all measured in situ using a WTW Oxi 330i/set. It is common practice when taking water samples to sample below the surface of the water. In the case of the study by Cox et al. (2005) the standard water quality parameters were taken 0.2m below the water surface using portable water quality meters, Martek 15m, YSI Grant 3800 and YSI Grant 6920.

As mentioned above, DO is a useful indicator for aquatic stress, however, more specific parameters are often used to analyse the demand for oxygen in a water body, including Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD is a measure of the oxygen depleting potential of organic and inorganic material within natural waters (Hudson et al., 2008). As described by Hudson et al. (2008) the BOD sample analysis is a biodegradation test which involves measuring the decrease in dissolved oxygen over a 5-21 day period, thus allowing the concentration of biodegradable material present, to be calculated. In the case of BOD, a higher value is indicative of contaminated water whereas a lower value indicates good water quality (Wen-bao and Dong-mei, 2009). Due to the

minimum five day delay in obtaining the results, attempts are being made to develop a laboratory or field test for BOD based on fluorescence spectroscopy which would deliver a result in ~1 min (Hudson et al., 2008). Studies, such as that by Cammack et al. (2004), have shown that fluorescence in certain spectral regions is associated with microbial activity and it is believed that by studying this, the microbial community's characteristics could be assessed. Currently, chemical oxygen demand (COD) is used to achieve a quicker measurement for oxygen consumption especially at many wastewater treatment facilities. This test involves the reduction of potassium dichromate, a strong oxidant, under highly acidic conditions and high temperature to measure oxygen demand (LaPara et al., 2000). In the study by Taner et al. (2011) COD was monitored using the open reflux method, this being an effective means of assessing the organic pollution load especially in water bodies where industrial discharge may be a problem.

Another indication of physical and chemical stress in water bodies are the nutrient concentrations, mainly nitrogen and phosphorus. As described by Brainwood et al. (2004), the conventional method for measuring total nitrogen is the Kjeldahl method which can be time consuming and complicated and the chemical processing involved is open to error. As a result of this, some researchers, including Brainwood et al. (2004), have used another method which utilises persulfate digestion to determine total nitrogen and total phosphorus. Persulfate digestion causes the oxidation of nitrogen (N) to nitrate ( $\text{NO}_3^-$ ) and the sample is then analysed for nitrate (Ferree and Shannon, 2001). Although there are improvements to the precision and sensitivity of the analysis associated with persulfate digestion the accuracy remains comparable to the Kjeldahl method and thus other options for nitrogen analysis have been sought (Frankovich and Jones, 1998). One promising method is second derivative spectroscopy which utilises a UV/Visible scanning spectrophotometer and represents a much simpler and faster procedure (Ferree and Shannon, 2001). Spectrophotometric methods have also been applied to phosphorus analysis where the reaction between orthophosphate ions with molybdate in an acidic medium to form the 12-molybdophosphoric heteropolyacid is used to determine the concentration of dissolved reactive phosphorus (Miro et al., 2003).

The concentration of chlorophyll-a can also yield information regarding the primary production occurring in freshwater aquatic environments (Brainwood et al., 2004). Brainwood et al. (2004) achieved this through the filtration of water samples in order to extract chlorophyll-a into acetone from the separated solids. Following this the extract was acidified

causing the denaturing of the chlorophyll-a protein. A difference in absorbance before and after the acidification was then detected, a change which could be attributed to the presence of chlorophyll-a. Cox et al. (2005) also analysed for chlorophyll-a, although using a different technique. In this study the water samples for chlorophyll-a analysis were filtered using 0.45µm Whatman GF/C filter paper, similar to the Brainwood et al. (2004) study, however the filter paper containing the retentate was then packaged in a plastic tube with preservative and covered using aluminium foil to prevent light entering the tube. These samples were then transported on ice to the laboratory where spectrophotometric analysis was used to determine the chlorophyll-a concentration.

Toxicant analysis is another important aspect of water quality management with the measurement of the concentrations of a range of heavy metals forming a large part of the process. Ivahnenko et al. (2001) discussed the use of a modified low-level trace-element ground-water sampling technique used by the US Geological Survey (USGS) in 1994. This method involves collecting samples in acid-washed, single-use, high density polyethylene disposable tubing with a single-use disposable 0.45 µm pore size capsule filter. As explained by Ivahnenko et al. (1996), the acid-wash used consisted of 5% nitric acid solution made using 8L of deionised water to 500mL of nitric acid. Nitric acid was used as opposed to hydrochloric acid because nitric acid is a stronger oxidant, which is required to remove sorbed trace elements, and it is generally free of trace elements. These sample bottles were suitably prepared, prior to having the sample put in them, using a sequential soapy water/ deionised wash triple external rinse. The careful preparation of the sampling equipment highlights the importance of preventing contamination when sampling for trace elements. Following collection, samples were then analysed using inductively coupled plasma-mass spectrometry (ICP-MS) for a suite of trace elements including cadmium, chromium, copper, lead, nickel and zinc. Although ICP-MS was used by Ivahnenko et al. (2001), other researchers have used different spectrometry approaches to analyse trace elements, indicating that no one method appears superior. While Parks et al. (2004) followed Ivahnenko's et al. (2001) approach, using an Agilent 7500c ICP-MS in helium collision mode to analyse for total chromium, Teasdale et al. (2003) utilised graphite furnace atomic absorption spectrometry (GFAAS) to measure the copper concentrations in water samples. Teasdale et al. (2003) collected water samples using low-density polyethylene bottles which had been washed using a 10% (v/v) solution of nitric acid and rinsed using large quantities of deionised water. Such preparation of sample bottles was also used by Baig et al. (2009), in the collection of water samples for the purpose of

arsenic analysis. In addition, as with the Ivahnenko et al. (2001) discussion of the USGS 1994 methodology, Baig et al. (2009) utilised 0.45µm filter paper during sample collection, although hydride generator atomic absorption spectrophotometry (HG-AAS) was used to complete the arsenic analysis. GFAAS, utilised by Teasdale et al. (2003), is also popular in the analysis of lead, although separation and preconcentration procedures are often needed before such analysis will be effective (Liang and Sang, 2008). Recently liquid-phase microextraction (LPME) has emerged as the most effective pre-treatment procedure and its use along with electro-thermal vaporisation inductively coupled plasma atomic emission spectrometry/mass spectrometry (ETV-ICP-AES/MS) or GFAAS has been accepted as an effective method of trace element analysis (Liang and Sang, 2008). Interestingly, Buck and Bruland (2005) employed a very different approach in their copper analysis, known as competitive ligand exchange-adsorptive cathodic stripping voltammetry (CLE-ACSV). In this method a ligand is added to the sample of known competition strength and it is allowed to equilibrate with the natural ligands present in the sample and the added dissolved copper concentrations. Following this the side reaction coefficient can be defined allowing the copper concentration to be found.

In addition to the analysis of trace element toxicants the measurement of ammonia is a valuable aspect in any water quality regime. Ammonia analysis includes spectrophotometric methods, of which three are used most commonly including indophenol blue method, the gas diffusion/acid-base indicator procedure and the use of Nessler's reagent, as well as titrations, potentiometric determinations, ammonia selective electrodes and carbon dioxide laser photocooustic spectroscopy (Van Staden and Taljaard, 1997). The gas diffusion/acid-base indicator procedure is a simple and convenient method, however accuracy and precision can be poor due to the presence of gas-permeable substances, such as carbon dioxide, in the sample. The indophenol blue method is a specific test for ammonia due to the fact that it is not influenced by organic nitrogen compounds or nitrite and nitrate. The procedure is also suitable for direct routine analysis of ammonia in both fresh and salt water and it is for these reasons that it was utilised by Van Staden and Taljaard (1997).

The third category provided by Wong (2006), microbial pathogens, is generally sampled using sterile disposable plastic bottles which are stored under cool conditions during transport to the laboratory (Santhiya et al., 2011). The samples are then cultured in the laboratory in order to determine the concentration of microorganisms in the water. For example, Plancherel

and Cowen (2007) used 1L autoclaved polycarbonate widemouth bottles to collect water samples ~10cm below the surface and transported them on ice to the laboratory. Using membrane filtration, the samples were then assayed onto nitrocellulose, 0.45µm pore size 47mm diameter filters where the filters for *Clostridium perfringens* were incubated anaerobically for 18-45h. *Enterococci* and the heterotrophic plate count as an indicator for particle-associated microbial indicator bacteria were also analysed. The *Enterococci* sample was assayed using membrane filter techniques as outlined in APHA (2005) whereby the culture plates are inverted and incubated for 48h at 41°C. The heterotrophic plate count was assayed again using membrane filter methods however it was incubated at 35°C for 48h.

#### **1.4 Limits of Detection and Water Quality Guidelines**

All of the above water quality parameters are assessed in accordance with a range of detection limits which explain the lowest value at which a result can be reported. As explained by Springer et al. (2007), different detection limits are reported depending upon the parameter being analysed and also the method used to determine the detection limit. For example, the Method Detection Limit (MDL) is most commonly found by analysing 7 replicates and it represents the “minimum concentration of an analyte that can be measured and reported with 99% confidence that the analyte concentration is greater than zero as determined by a specific laboratory,” (Springer et al., 2007). The Practical Quantitation Limit (PQL), also called the Limit of Reporting (LOR), is generally derived by multiplying the MDL by 5 and it represents the concentration that reputable laboratories are able to detect under routine conditions. During some analyses the PQL needs to be raised due to the interference of salt, which can disrupt metal analysis and highly coloured waters, which disrupts nutrient analysis (Springer et al., 2007).

In addition to observing whether results are within Laboratory Limit of Reporting, comparison of the results with established water quality standards is also a very important stage of the assessment process. The most well known guidelines are the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, the latest version having been released in October 2000 and representing a collaborative work between *Australian and New Zealand Environment and Conservation Council (ANZECC)* and *Agriculture and Resource Management Council of Australia and New Zealand*. The central purpose of these guidelines is “to provide an authoritative guide for setting water quality objectives required to sustain the



current or likely future environmental values [uses] for natural and semi-natural water resources in Australia and New Zealand,” (ANZECC, 2000). They can be employed by a variety of users from governments and industry professionals to the general community in the formulation of their own guidelines which are relevant to the catchment in which they are operating. The ANZECC guidelines are concerned with the conservation value of water ways and thus are generally not supposed to be applied to stormwater or recycled water. The Australian Runoff Quality Guidelines (Wong, 2006) by comparison, are intended for use with stormwater and urban runoff assessment. In addition, control site data can be utilised to give an indication of the background concentrations of various water constituents which may be present in a location. A combination of the latter two guidelines would prove effective in assessing any water quality data gathered from stormwater analysis.

### **1.5 Present Study**

The purpose of this study was to determine the effect of different kinds of gross pollutant traps (GPTs) on stormwater quality within the Sutherland Shire. The study involved the examination of six different SQIDs which have been installed in a variety of different locations across the Sutherland Shire. In order to determine the overall health of the waterways and the operational capability of the SQID installations, a broad range of water quality parameters were selected for analysis. The water quality parameters used were pH, electrical conductivity, dissolved oxygen, temperature, suspended solids (SS), arsenic, cadmium, chromium, copper, nickel, lead, zinc, ammonia, nitrite and nitrate, total Kjeldahl nitrogen (TKN), total nitrogen, total phosphorus, biochemical oxygen demand (BOD) and *Enterococci*. The trends observed in these data along with trends in historical data, collected irregularly since 1994, were correlated with weather data to observe how the SQIDs affect water quality with varying rainfall intensities and flow conditions. The water quality data were combined with sediment grainsize analysis data to illustrate the relative differences between sediment collected at the inflow and that collected from the outflow. From this analysis the most effective SQID could be determined along with the most informative parameter as an indicator of overall water quality at the various locations. This information was then used in a discussion of how the results could possibly impact the management of stormwater in Sutherland Shire and the factors controlling water quality. Finally, consideration was given to the most appropriate method for presenting the information to the community from the perspective of potential human and ecological health impacts.

Although the literature appears devoid of any detailed investigations concerning stormwater within the Sutherland Shire, a number of similar case studies do exist from other parts of the world, which could be considered relevant examples of the kind of research being completed here. For example, in the study by Boeder and Chang (2008), the influence of land cover change and urban storm water management on oxygen demand variables was examined for the Rock Creek basin and sub-basins. Water quality regulations governing the Rock Creek basin ensure that the damaging effects of urbanisation on waterways are mitigated, through the construction of an extensive system of stormwater drains to manage runoff, as well as stormwater quality control and storage systems such as drains, ponds and detention basins. In this sense the Rock Creek area is similar to the Sutherland Shire where considerable effort is invested in the improvement of stormwater quality. Additionally, the Rock Creek study employed a long temporal dataset stretching over ten years and likewise this study will examine historical data from 1994 to the present. The standardised assessment of multiple stormwater treatment sites, as seen in this study, was utilised by Hatt et al. (2009) in the examination of three separate field-scale biofiltration systems. Flow and water quality monitoring was conducted to assess how these systems function to enable the reduction of pollutants and retention of flow. Furthermore, the role that flow variability plays in pollutant removal was addressed. Such an approach resembles what was undertaken in this study to determine the relative effectiveness of different SQID installations. As with the current study, Hatt et al. (2009) analysed samples for a variety of water quality parameters including, total suspended solids, total phosphorus, total nitrogen, nitrate/nitrite, copper, cadmium, lead and zinc.

## 2. Materials and Methods

### 2.1. Site Description

According to the Sutherland Shire Council (2011), Sutherland Shire is located 26 km south of the Sydney CBD and represents the southern coastal border of the Sydney Metropolitan area. It is the second largest Local Government Area by population in NSW with an estimated resident population of 220 835 as at 30 June 2010. Sutherland Shire covers approximately 370 square kilometres and incorporates a variety of environments including beaches, parklands and national parks. Typically, the area is predominately residential, although industrial, commercial and rural areas represent important land uses also. Two major rivers and their associated catchments exist in the Sutherland Shire, these being the Georges River and the Hacking River. As shown by Map 2.1, the sites selected for water quality testing in this study are spread across the Sutherland Shire and include sites within both major river catchments. A description of these sites according to Sutherland Shire Council (2011) has been provided below. Note, the geology, soil type and zoning maps included below will be discussed in further detail in Chapter 4.

Mianga Avenue Wetland is located near the Engadine railway station on the edge of the Royal National Park (Maps 2.2 and 2.3). It was designed purposely to treat water coming from the urban catchment before it entered the Royal National Park. For this reason it has large trash racks to collect rubbish and a relatively deep sediment collection pit (Photo 2.1). The wetland usually holds quite a large amount of water which flows steadily from the outflow (Photo 2.2).



Photo 2.1 Mianga Avenue Wetland Inflow.



Photo 2.2 Mianga Avenue Wetland Outflow.

Cronulla Beach GPT flows into the ocean (Photo 2.4) at the southern end of Cronulla beach (Maps 2.8 and 2.9). It is installed beneath the concrete walkway, which runs along the beach, and is accessed via a series of grates (Photo 2.3). The GPT's main pollutant collection mechanism is through the use of a trash rack. There is a shower located adjacent to the grate covering the inflow access point for this GPT. The shower is used by the public coming off the beach and as such a large amount of sand is washed into the inflow of the GPT. This would be necessary to consider when analysing any sediment samples from the site.



Photo 2.3 Cronulla Beach GPT Inflow.



Photo 2.4 Cronulla Beach GPT Outflow.

Gunnamatta Bay GPT is located at the northern end of Gunnamatta Bay at Tonkin Park (Maps 2.14 and 2.15). It was designed specifically for stormwater treatment but represents only a very simple design with a mesh barrier, designed to collect gross pollutants, located in an underground chamber (Photo 2.5). It does not include any sediment collection technology as such and incorporates a large outflow which opens onto Gunnamatta Bay (Photo 2.6).



Photo 2.5 Gunnamatta Bay GPT Inflow.



Photo 2.6 Gunnamatta Bay GPT Outflow.



Still Creek Detention Basin located at Mina Road, Menai, was not designed for stormwater treatment. Rather, it was built to control flooding and sediment during the construction of the adjacent homes (Maps 2.20 and 2.21). The site is approximately 104 m long with a trash rack situated at the inflow (Photo 2.7) and a raised outlet at the opposite end of the basin (Photo 2.8). The raised outlet is a problem as it prevents the regular flow of water through the system. Under normal conditions the water level is below the outlet and so flow only occurs following large rain events, when excess water can flood the basin and pass into the flood control drains located adjacent to the outflow.



Photo 2.7 Still Creek Detention Basin Inflow.



Photo 2.8 Still Creek Detention Basin Outflow.

Burnum Burnum Detention Basin Reserve at Woronora is the most recent site to be placed on the Sutherland Shire Council sampling program. It was built by the Roads and Traffic Authority following the construction of the Woronora Bridge, which crosses the Woronora River at Woronora (Maps 2.26 and 2.27). Its purpose is to control chemical spills, which could potentially occur on the bridge, rather than stormwater quality improvement, and therefore has an unusual inflow structure (Photo 2.9). The basin is approximately 95m long with a small trash rack covering the outlet (Photo 2.10). It has numerous problems associated with it including low flow, due to the outflow being below high tide. Furthermore, fish enter the basin during high tide and can become trapped. During one particular event, the breakdown of massive amounts of dead algae in the basin caused a huge drop in dissolved oxygen levels, resulting in the death of large numbers of fish trapped in the system. The result was a very offensive smell and a dirty clean-up for the workers involved.



Photo 2.9 Burnum Burnum Detention Basin Inflow.



Photo 2.10 Burnum Burnum Detention Basin Outflow.

Tudar Road Wetland at Jannali was specifically designed as a stormwater treatment system. It fully treats 40% of stormwater from the catchment and will partially treat the remaining 60%. Water is held in the wetland for 48 hours following rain or storms. At the inlet is a GPT to collect coarse sediment, litter and organic matter (Photo 2.11). The water can then move to a deep water zone where fine sediment is trapped and UV penetration can occur for the purpose of disinfection. The water then moves through a reed bed which removes nutrients, heavy metals, oil, grease and chemicals. At the outlet is a V-notch weir which controls the water level in the wetland and oxygenates the clean water as it releases it from the system (Photo 2.12). In the event of a large flow the spillway can direct water into the existing water course. Currently the reed bed is overgrown and requires harvesting. This is necessary to prevent the release of phosphorus and nitrogen, which the reeds have removed, back into the system if they die and to maintain the open water section for UV penetration. It is comforting to note that approximately 95% of the vegetation in the wetland is native.

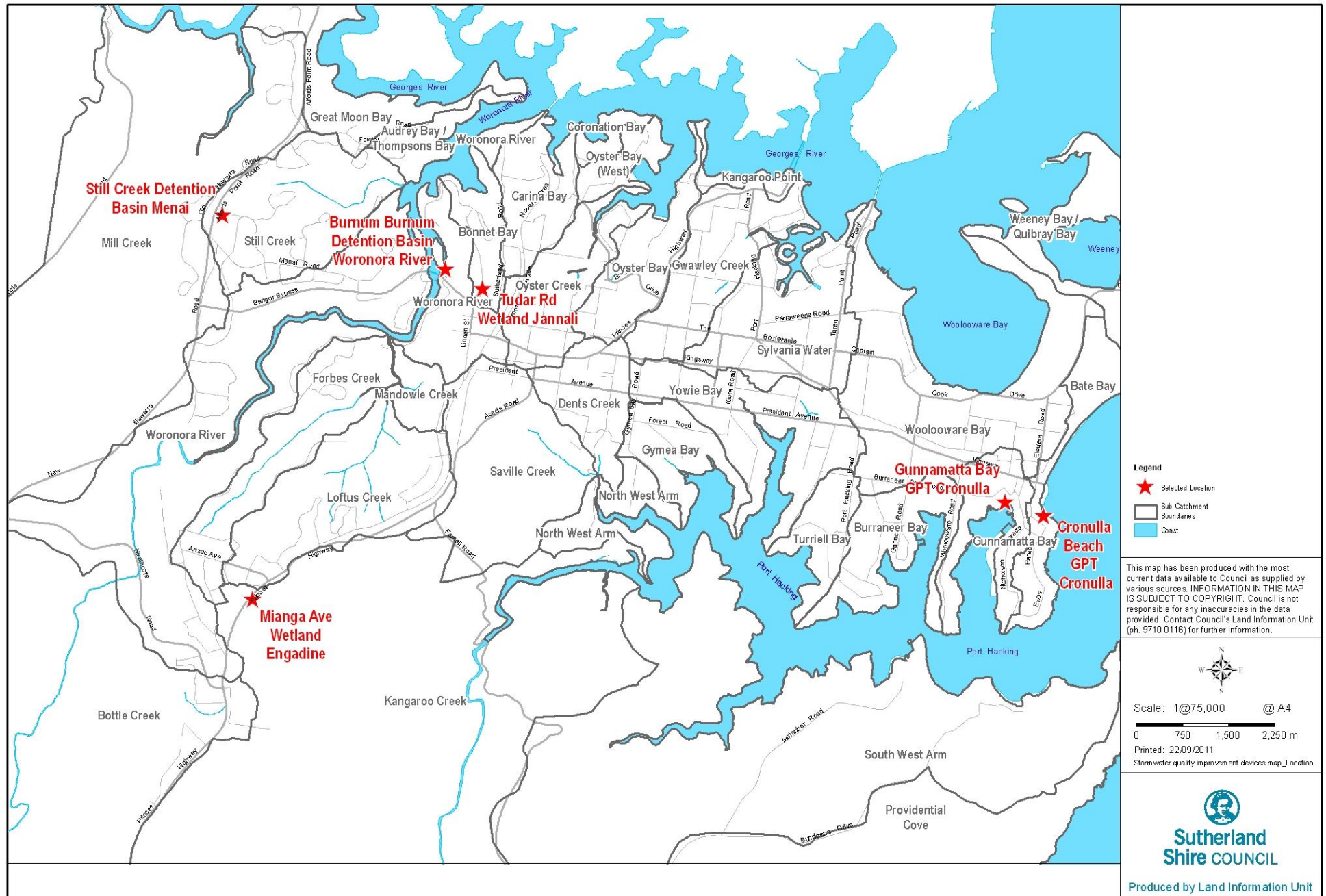


Photo 2.11 Tudar Road Wetland Inflow.



Photo 2.12 Tudar Road Wetland Outflow.





Map 2.1 Stormwater Quality Improvement Device Locations.





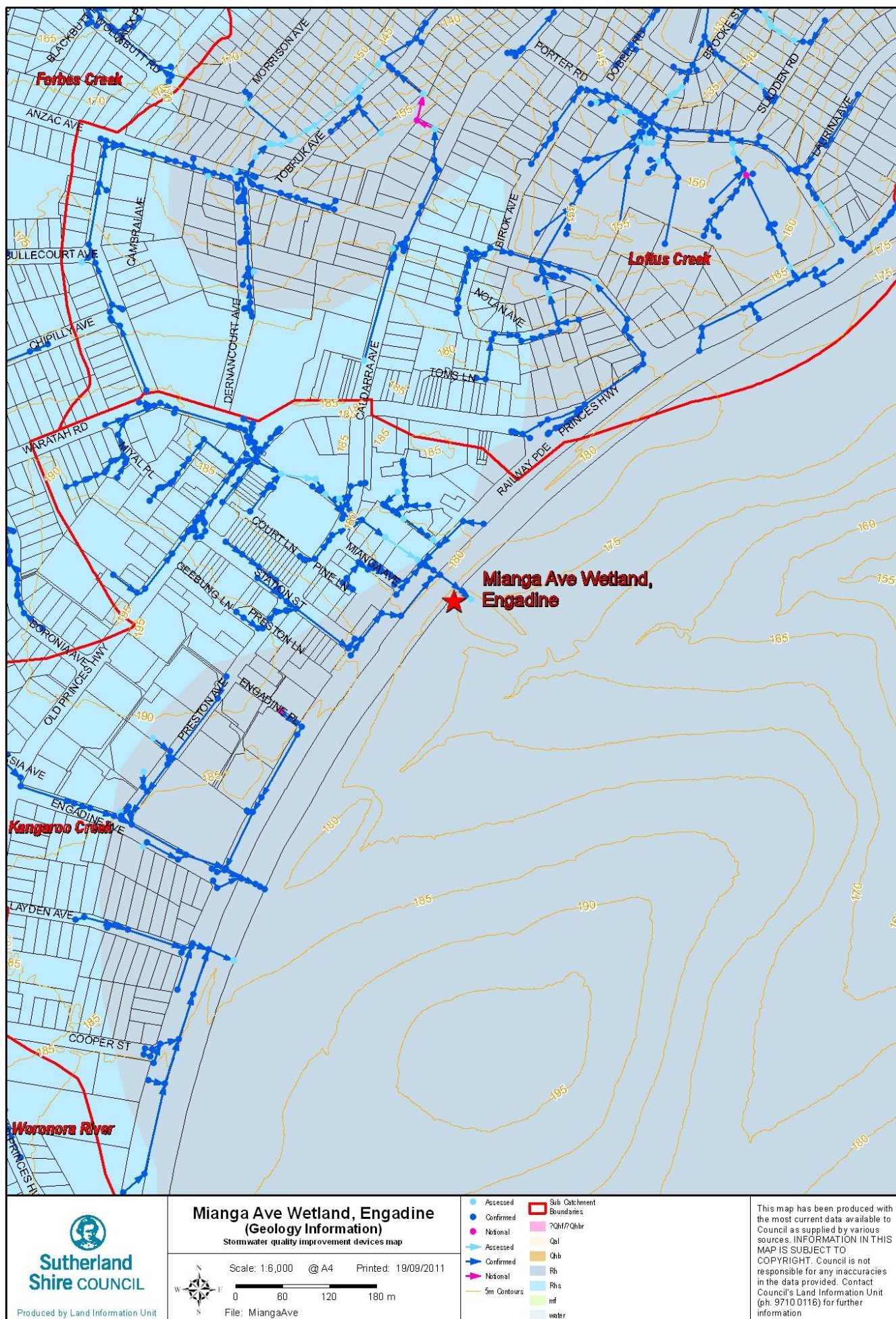
Map 2.2 Mianga Avenue Wetland Aerial Photograph 2001.





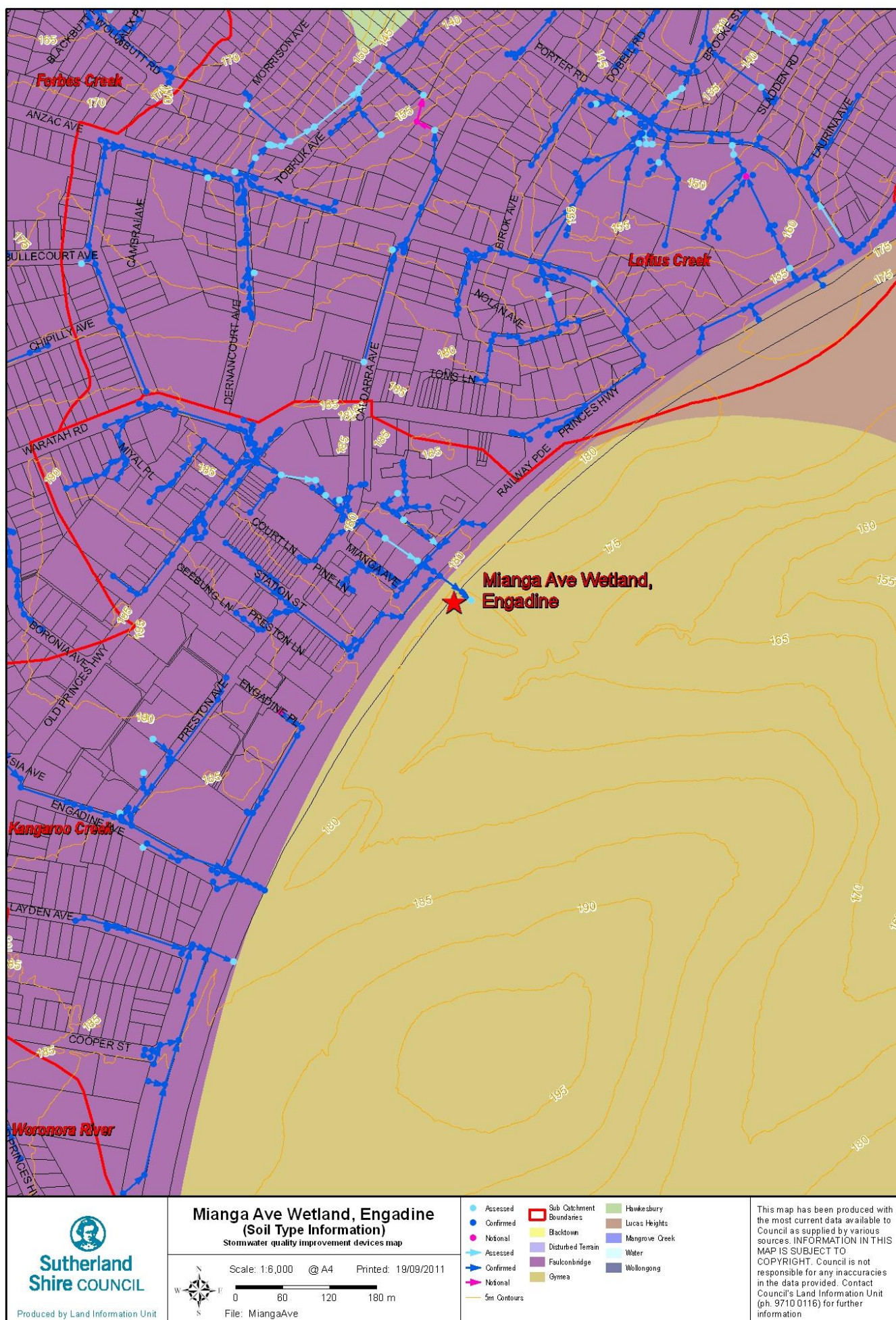
Map 2.3 Mianga Avenue Wetland Aerial Photograph 2010.





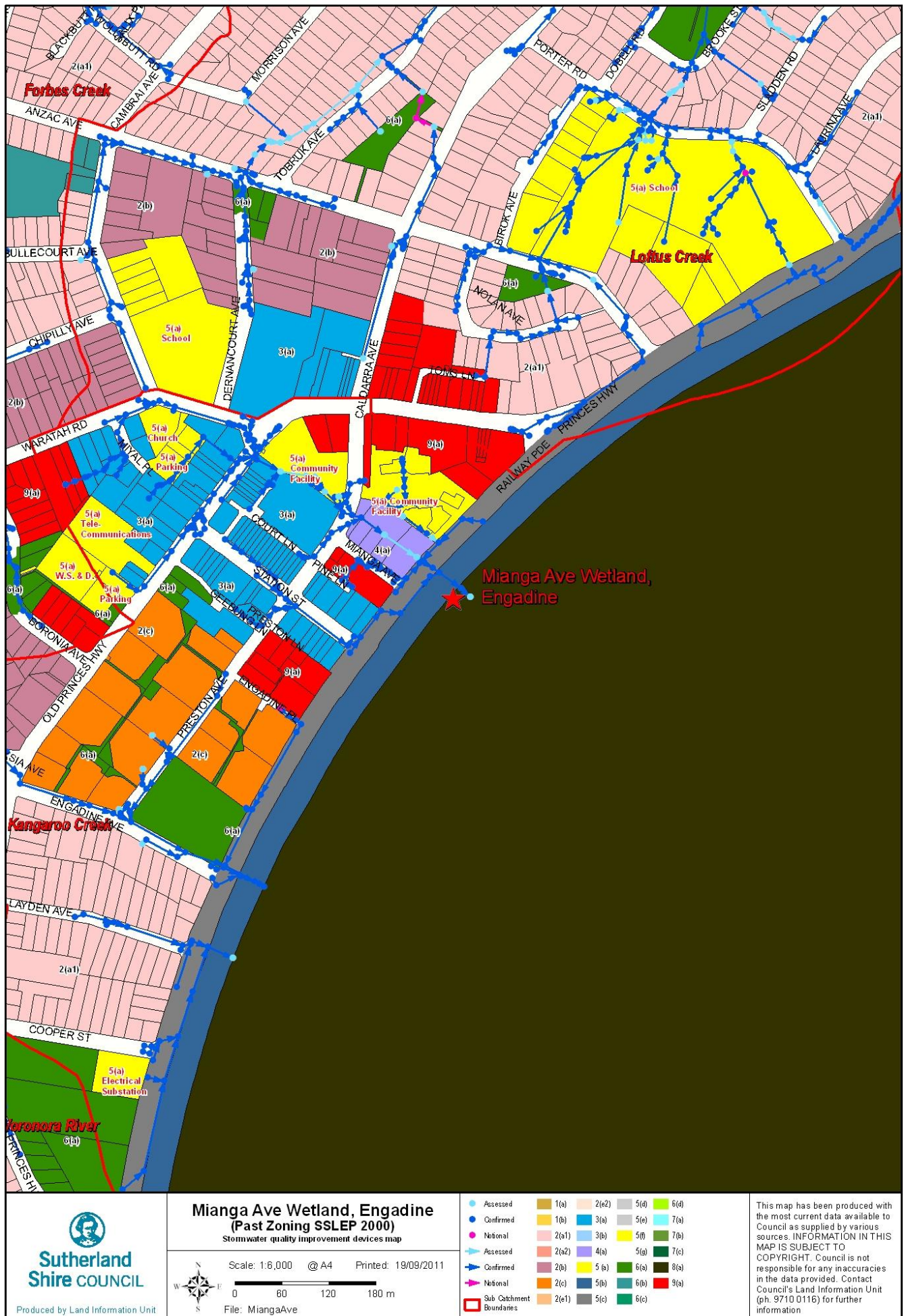
Map 2.4 Mianga Avenue Wetland Geology. Note Appendix 1 for Legend Description.





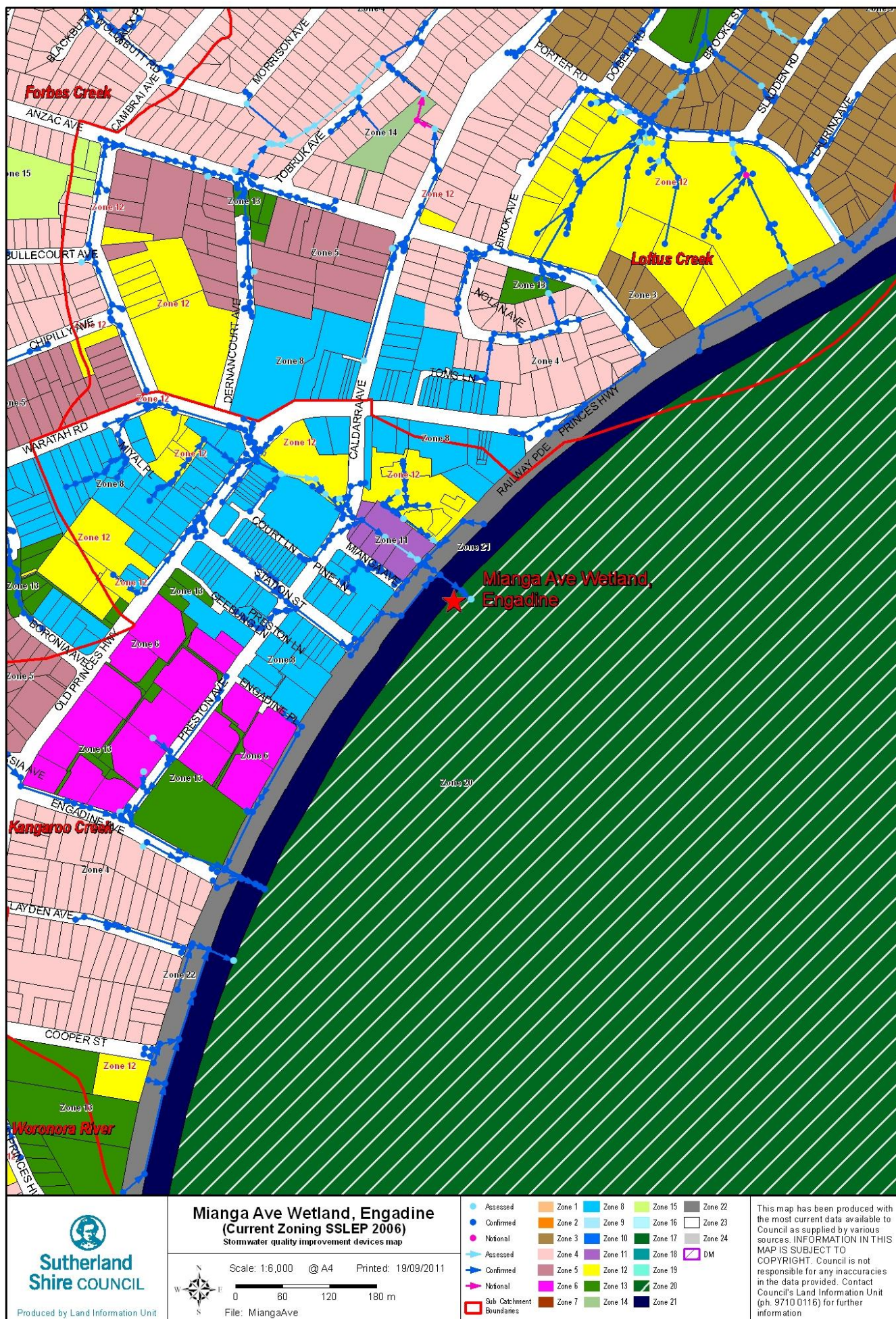
This map has been produced with the most current data available to Council as supplied by various sources. INFORMATION IN THIS MAP IS SUBJECT TO COPYRIGHT. Council is not responsible for any inaccuracies in the data provided. Contact Council's Land Information Unit (ph. 9710 0116) for further information





Map 2.6 Mianga Avenue Wetland Past Zoning SSLEP 2000. Note Appendix 2 for Legend Description.





Map 2.7 Mianga Avenue Wetland Current Zoning SSLEP 2006. Note Appendix 3 for Legend Description.





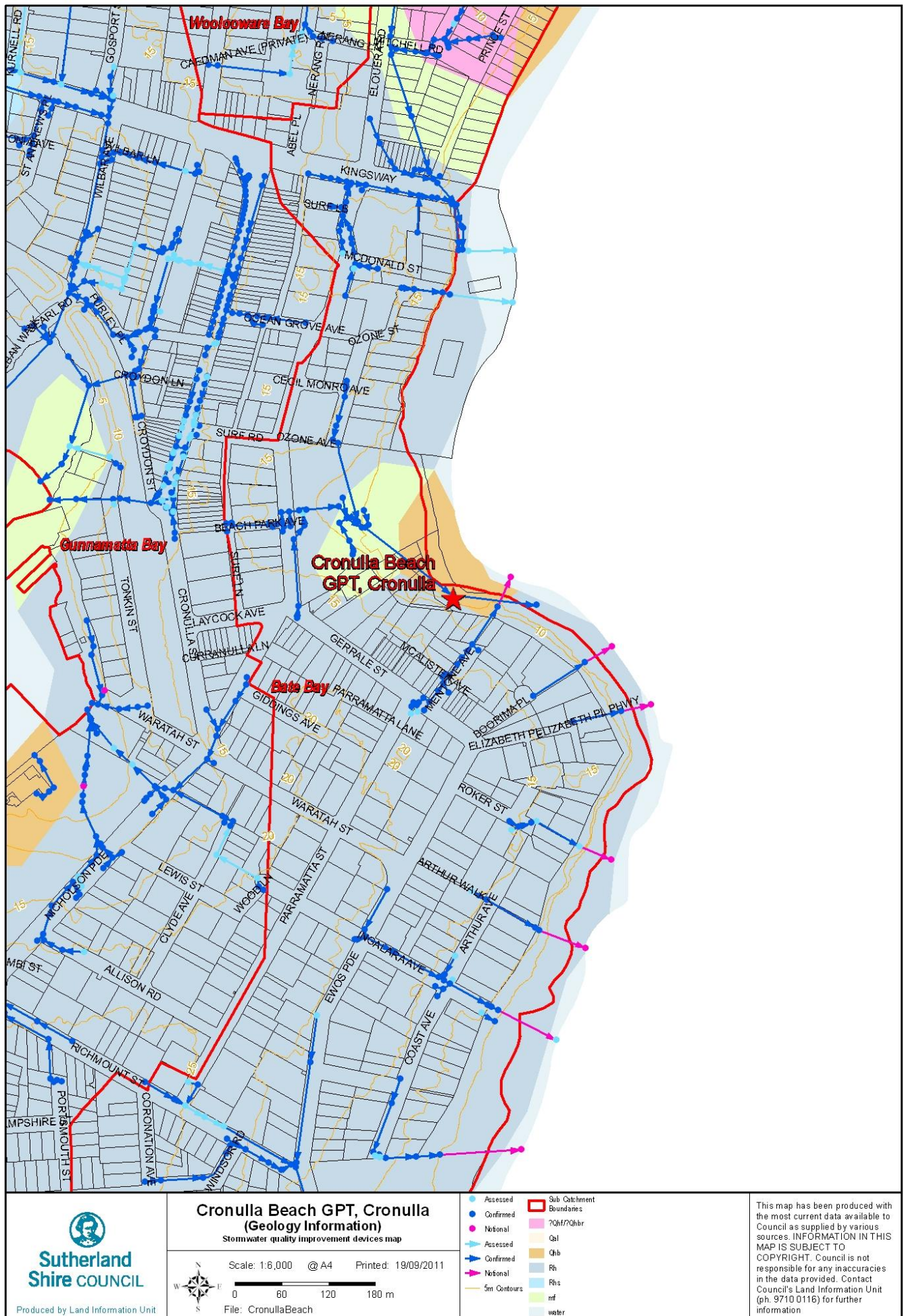
Map 2.8 Cronulla Beach GPT Aerial Photograph 2001.





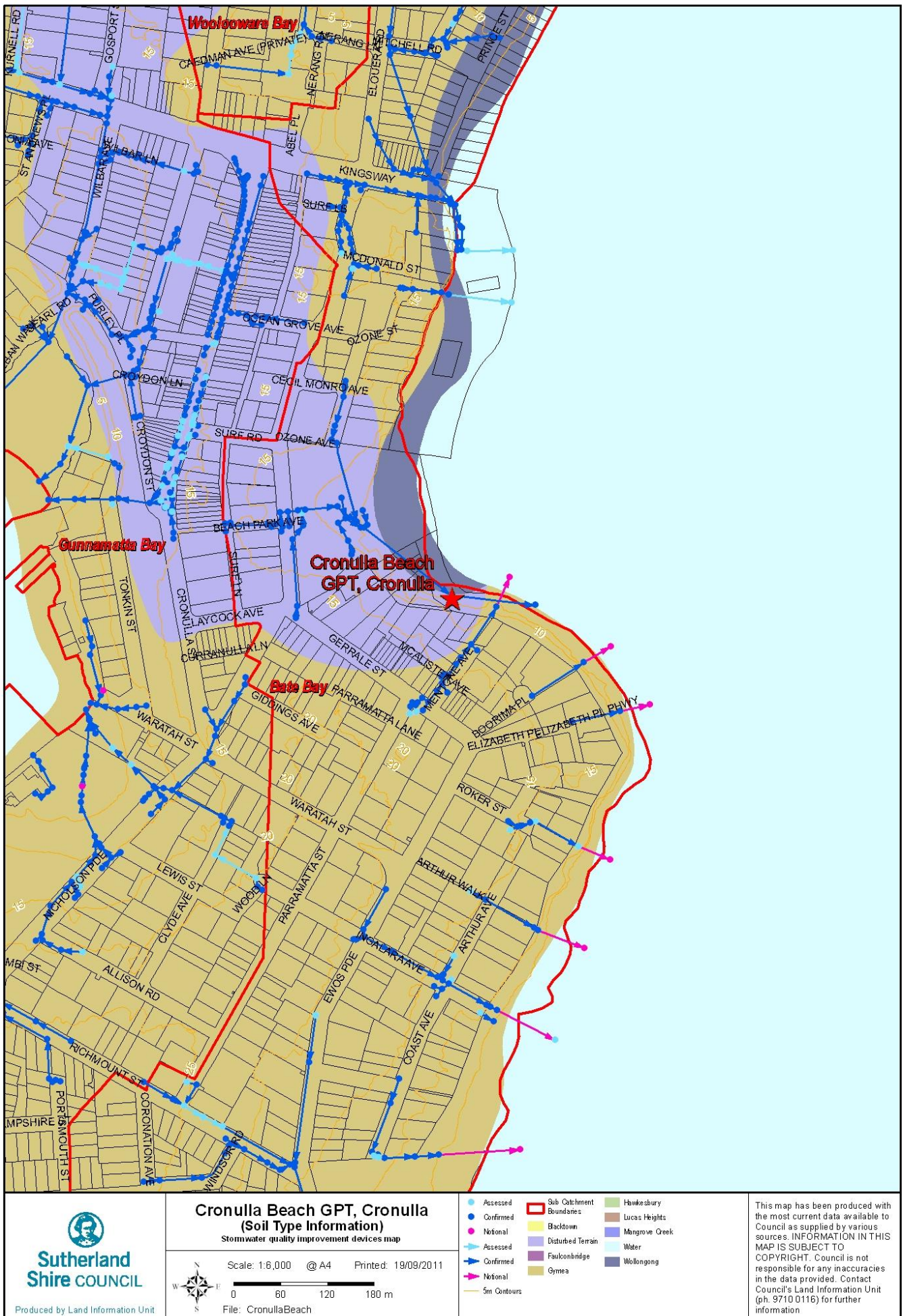
Map 2.9 Cronulla Beach GPT Aerial Photograph 2010.





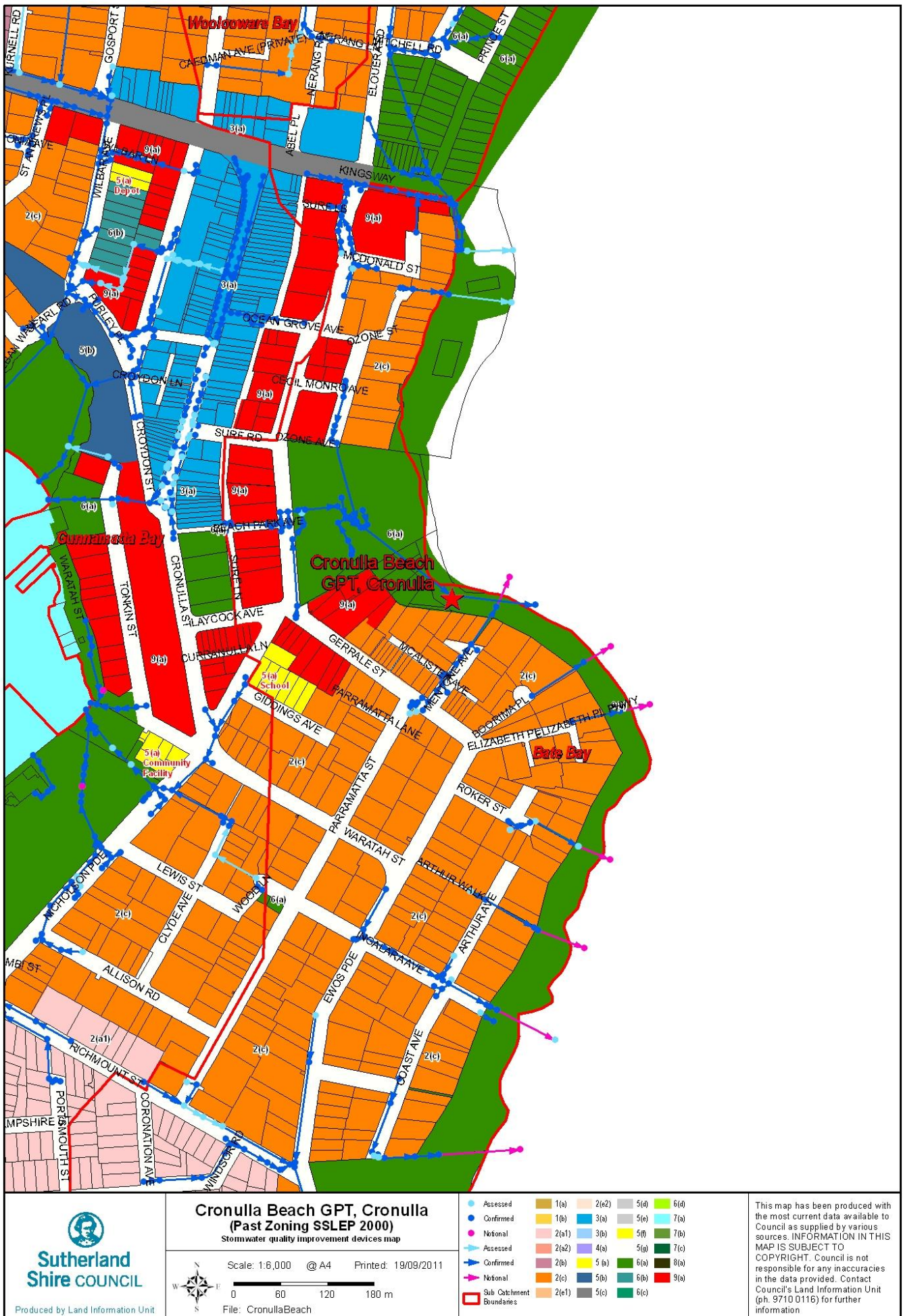
Map 2.10 Cronulla Beach GPT Geology. Note Appendix 1 for Legend Description.





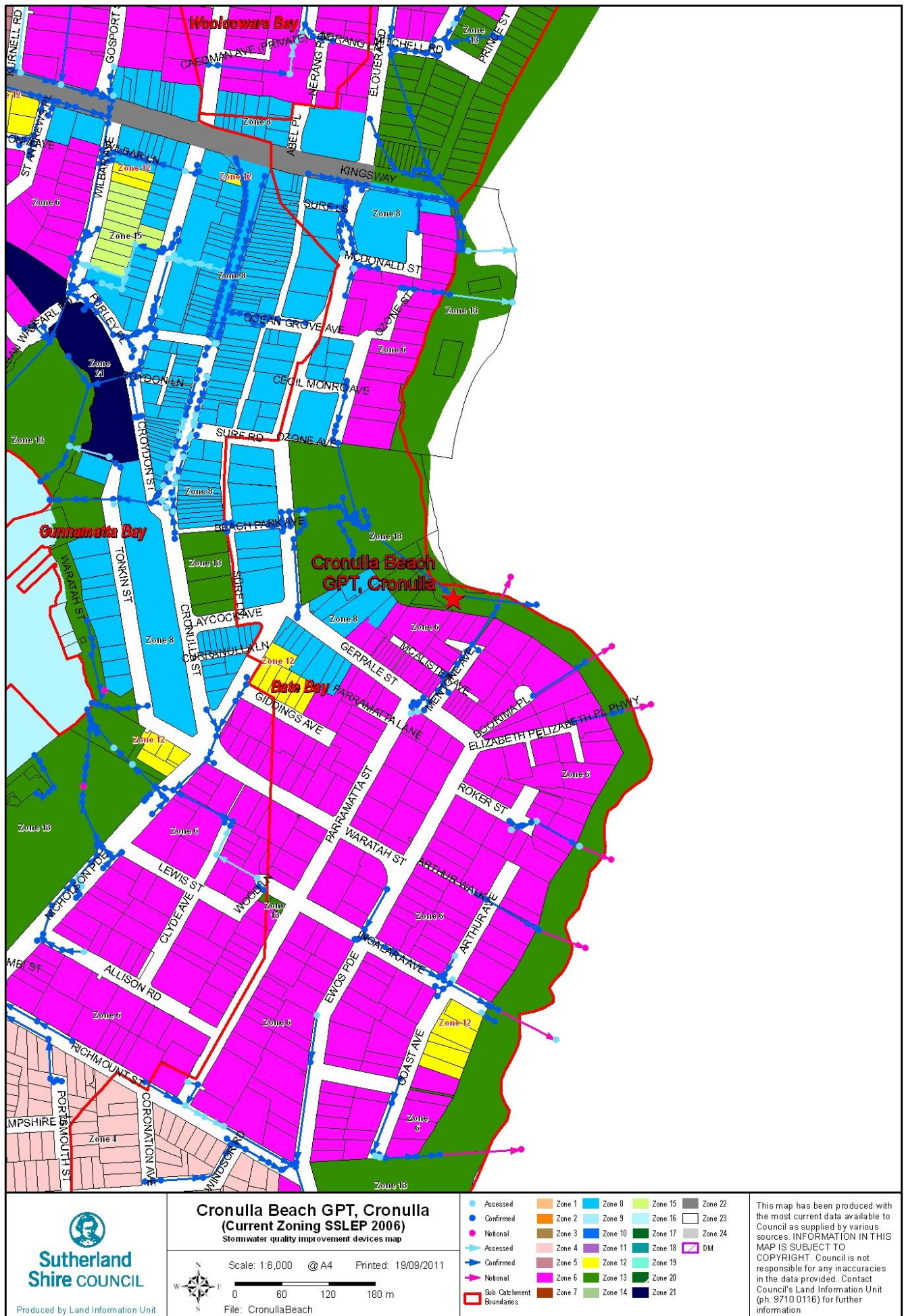
Map 2.11 Cronulla Beach GPT Soil Types.





Map 2.12 Cronulla Beach GPT Past Zoning SSLEP 2000. Note Appendix 2 for Legend Description.





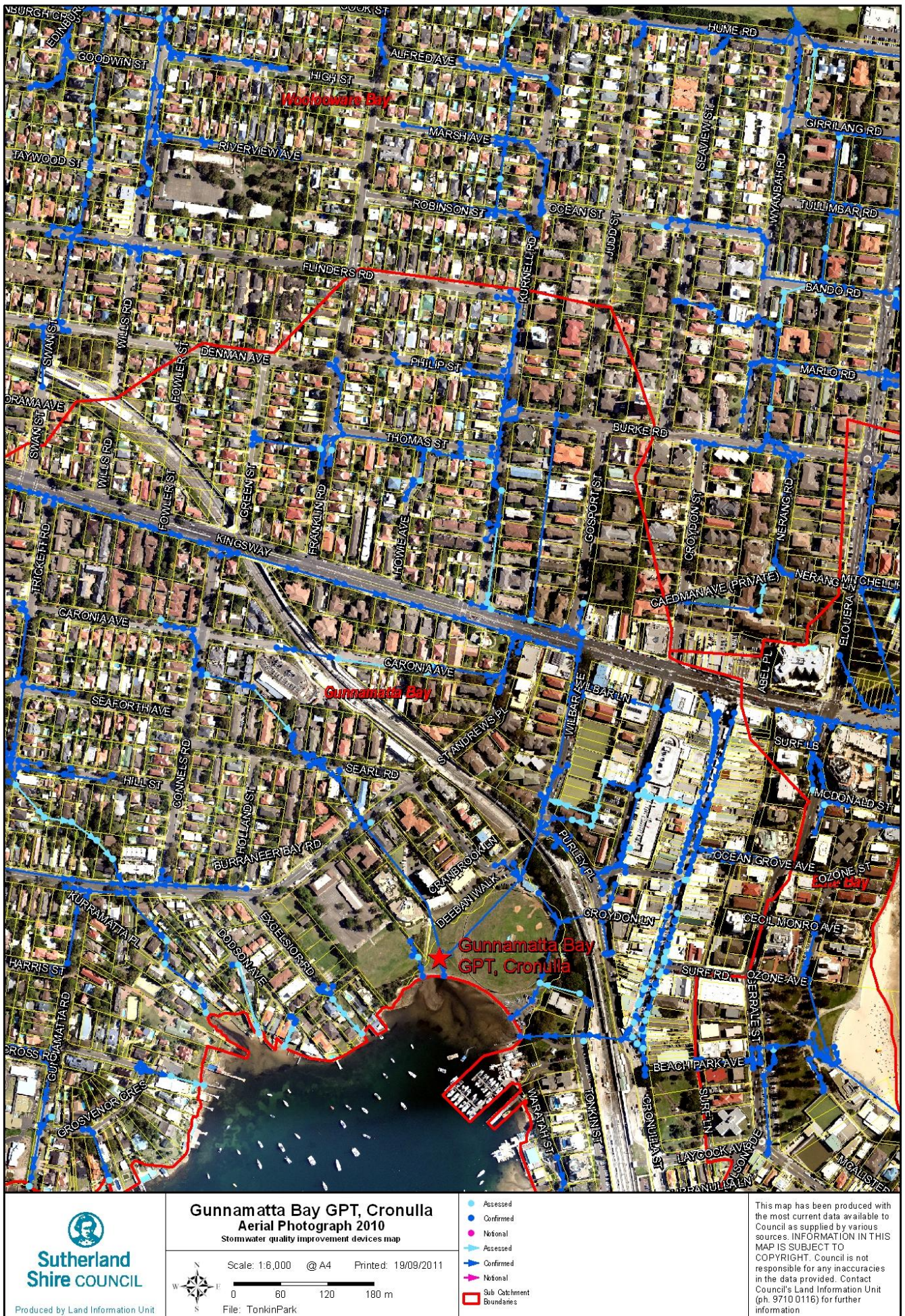
Map 2.13 Cronulla Beach GPT Current Zoning SSLEP 2006. Note Appendix 3 for Legend Description.





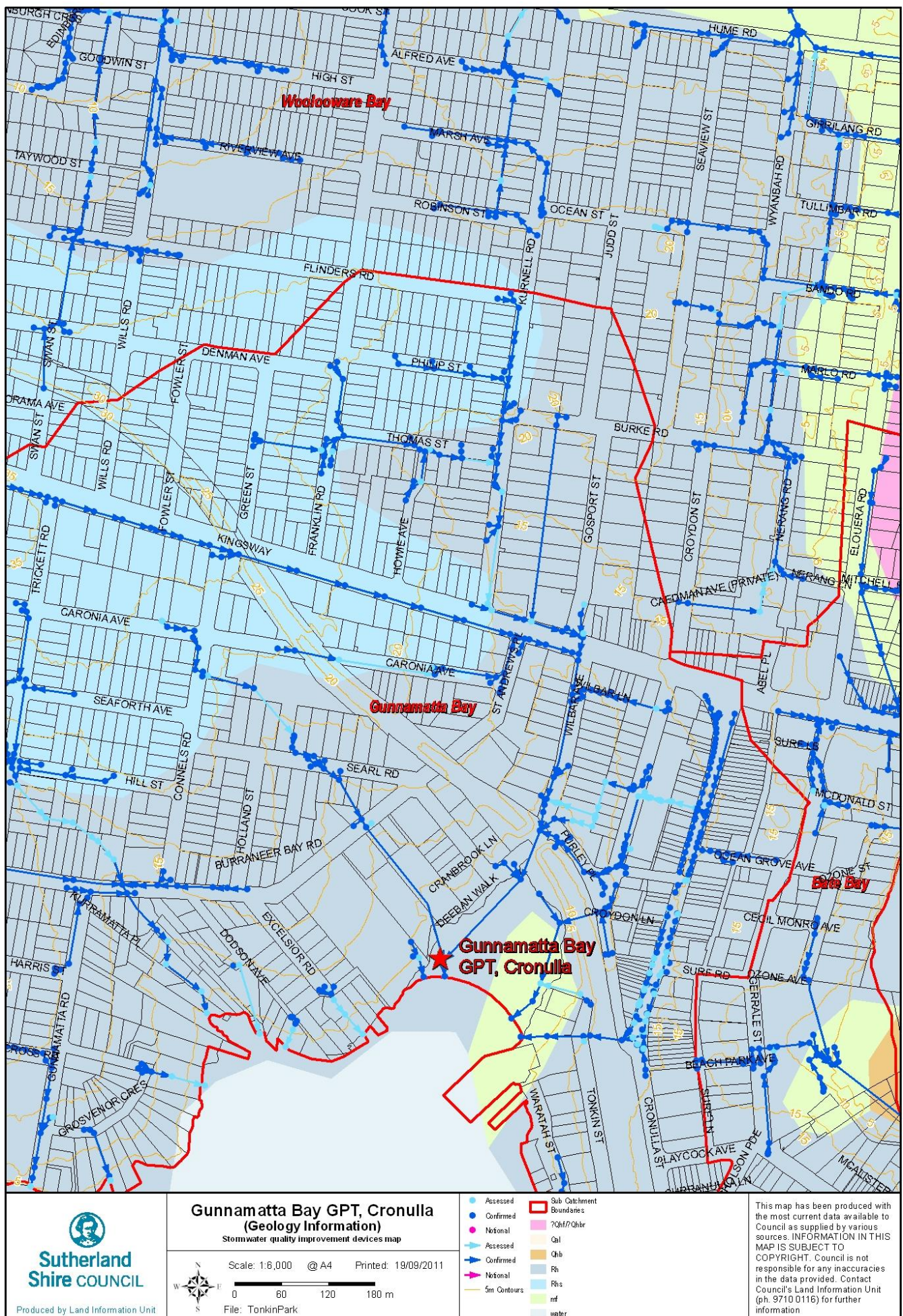
Map 2.14 Gunnamatta Bay GPT Aerial Photograph 2001.





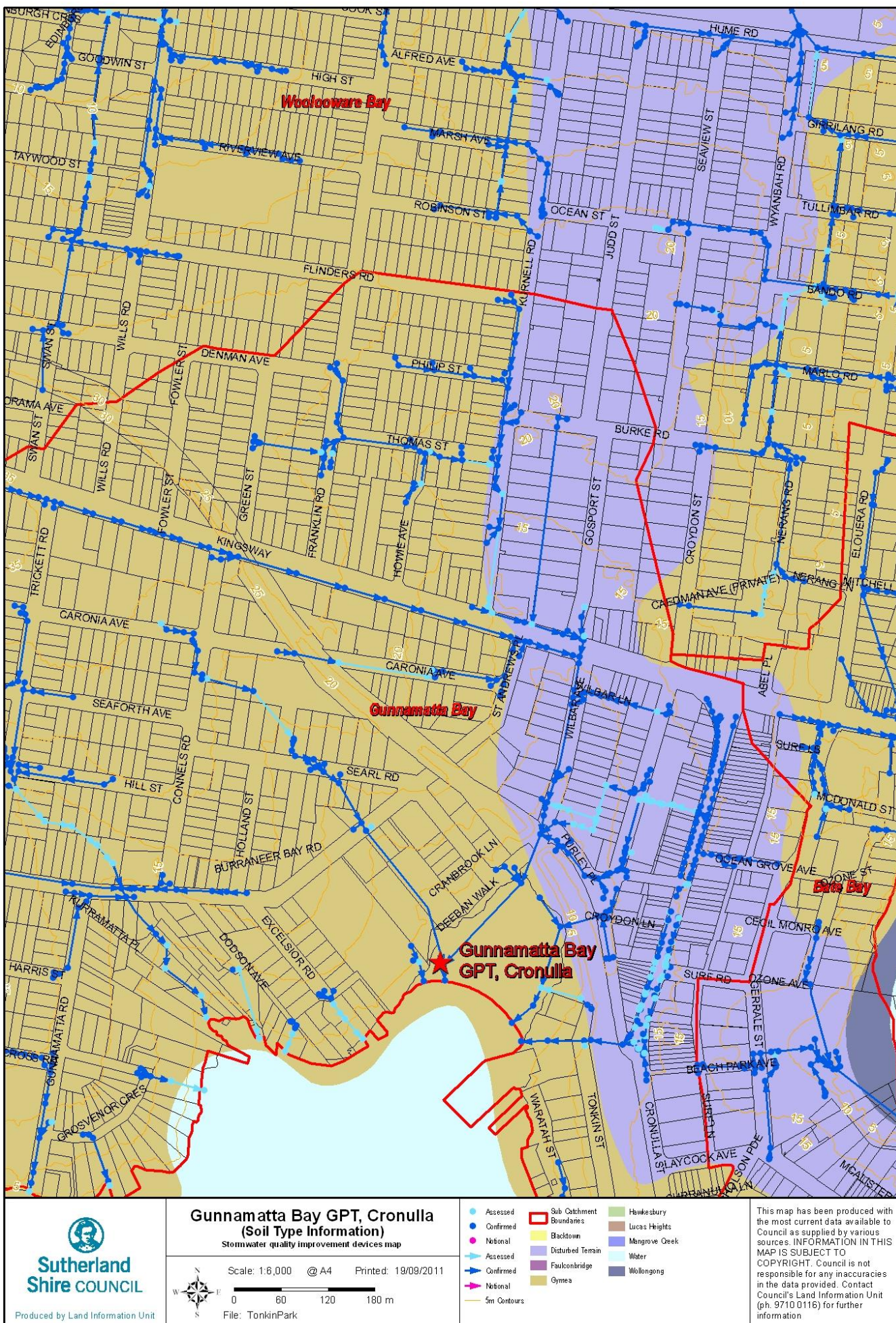
Map 2.15 Gunnamatta Bay GPT Aerial Photograph 2010.





Map 2.16 Gunnamatta Bay GPT Geology. Note Appendix 1 for Legend Description.



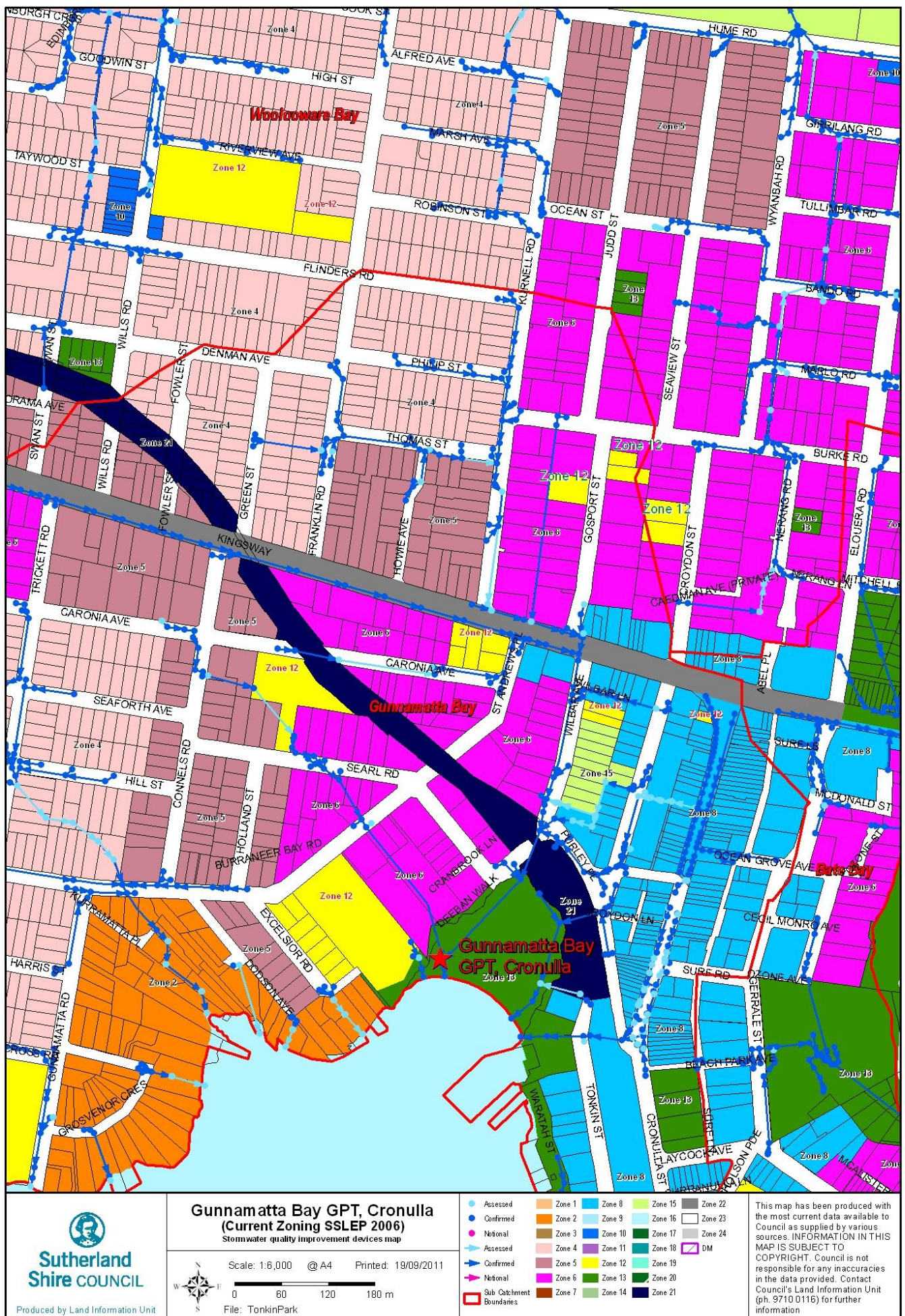


Map 2.17 Gunnamatta Bay GPT Soil Type.



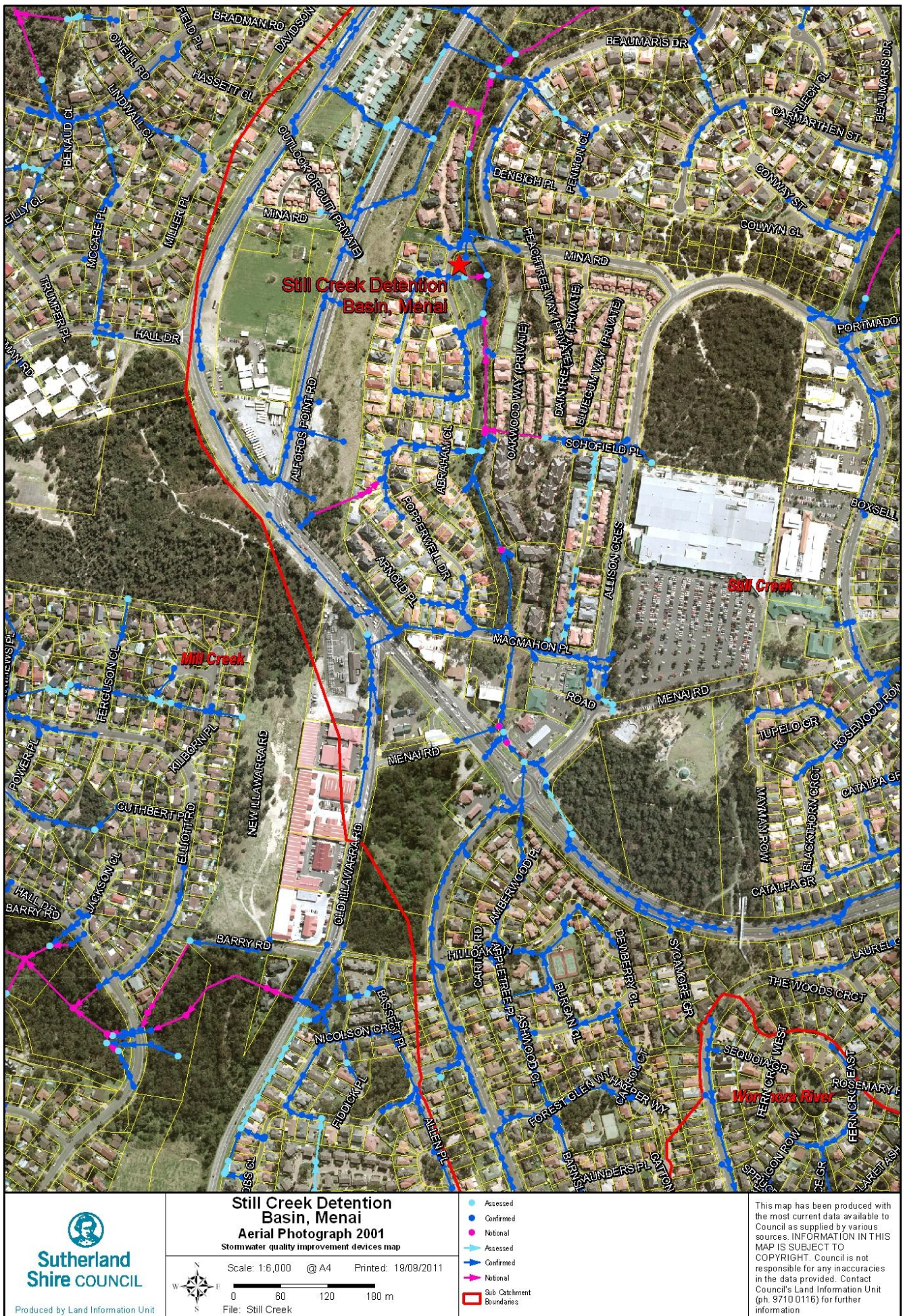
Map 2.18 Gunnamatta Bay GPT Past Zoning SSLEP 2000. Note Appendix 2 for Legend Description.





Map 2.19 Gunnamatta Bay GPT Current Zoning SSLEP 2006. Note Appendix 3 for Legend Description.





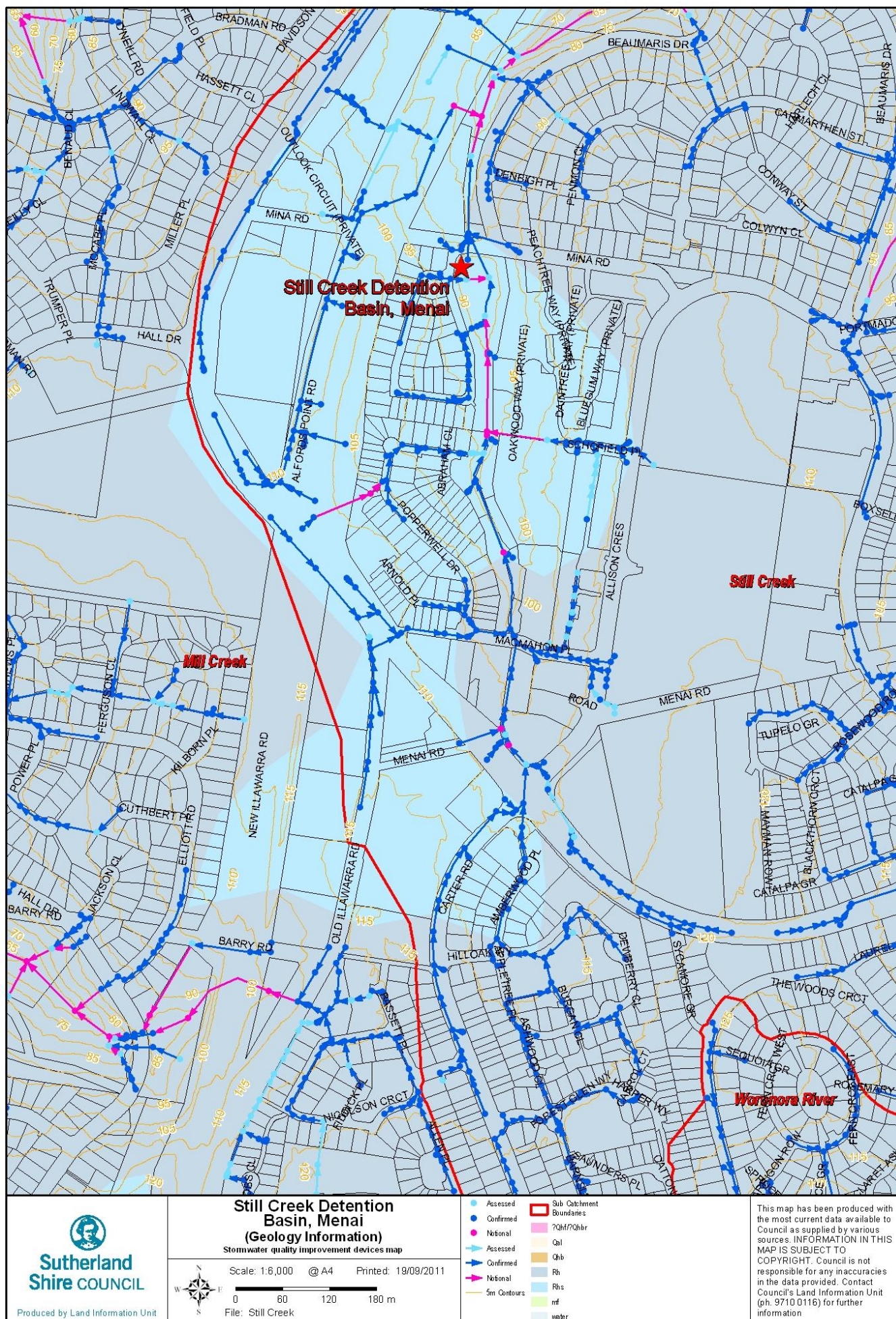
Map 2.20 Still Creek Detention Basin Aerial Photograph 2001.





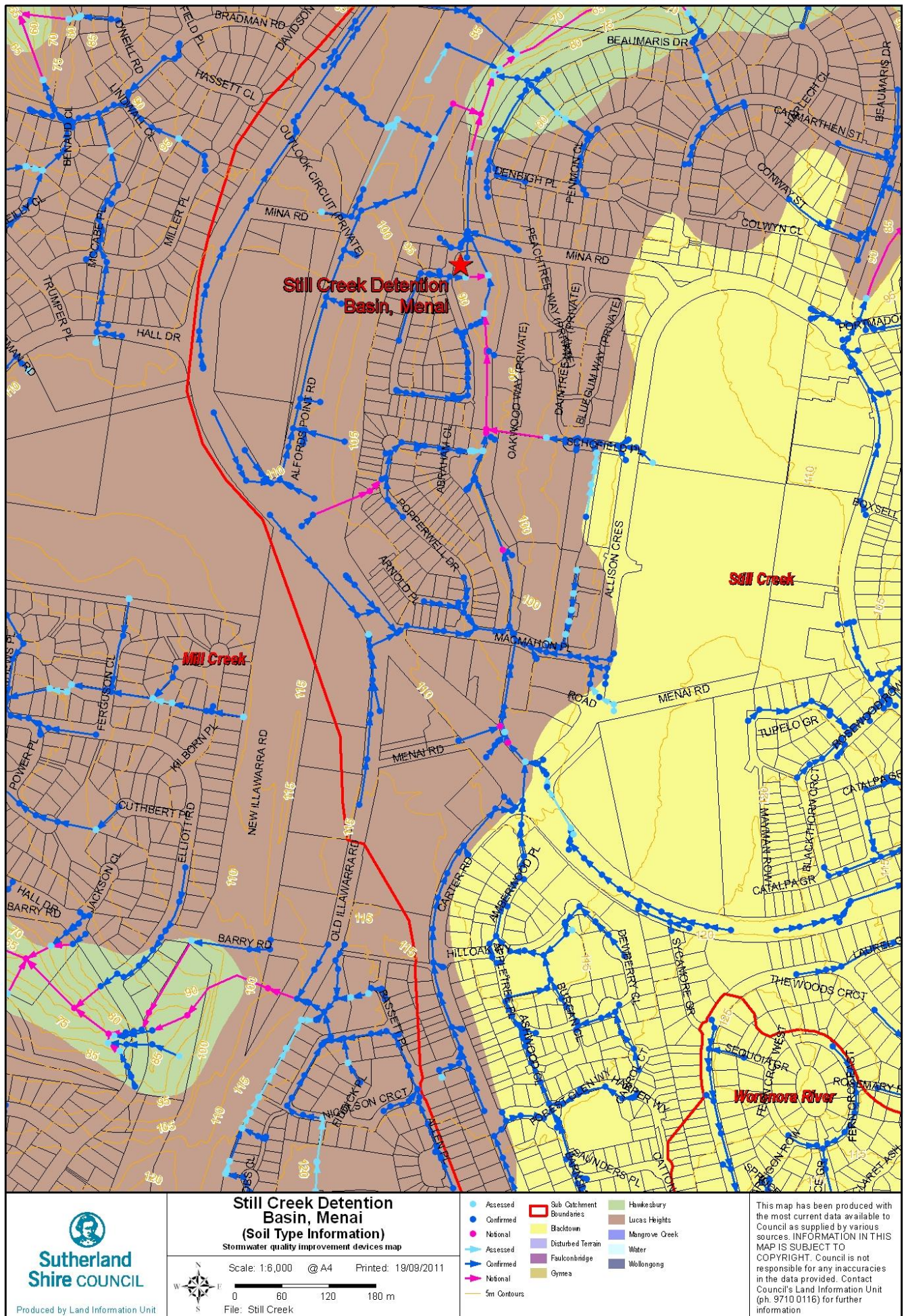
Map 2.21 Still Creek Detention Basin Aerial Photograph 2010.





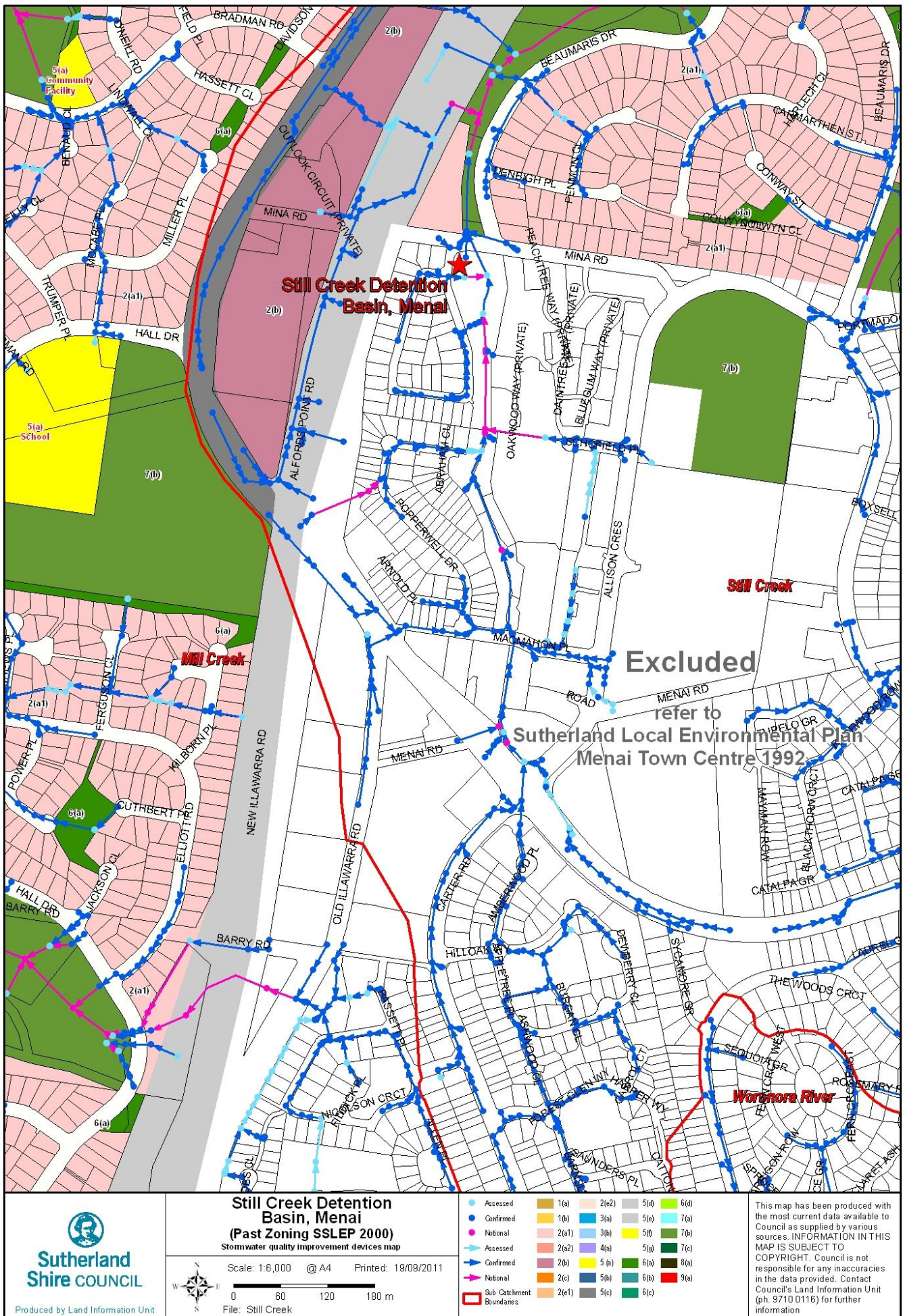
Map 2.22 Still Creek Detention Basin Geology. Note Appendix 1 for Legend Description.





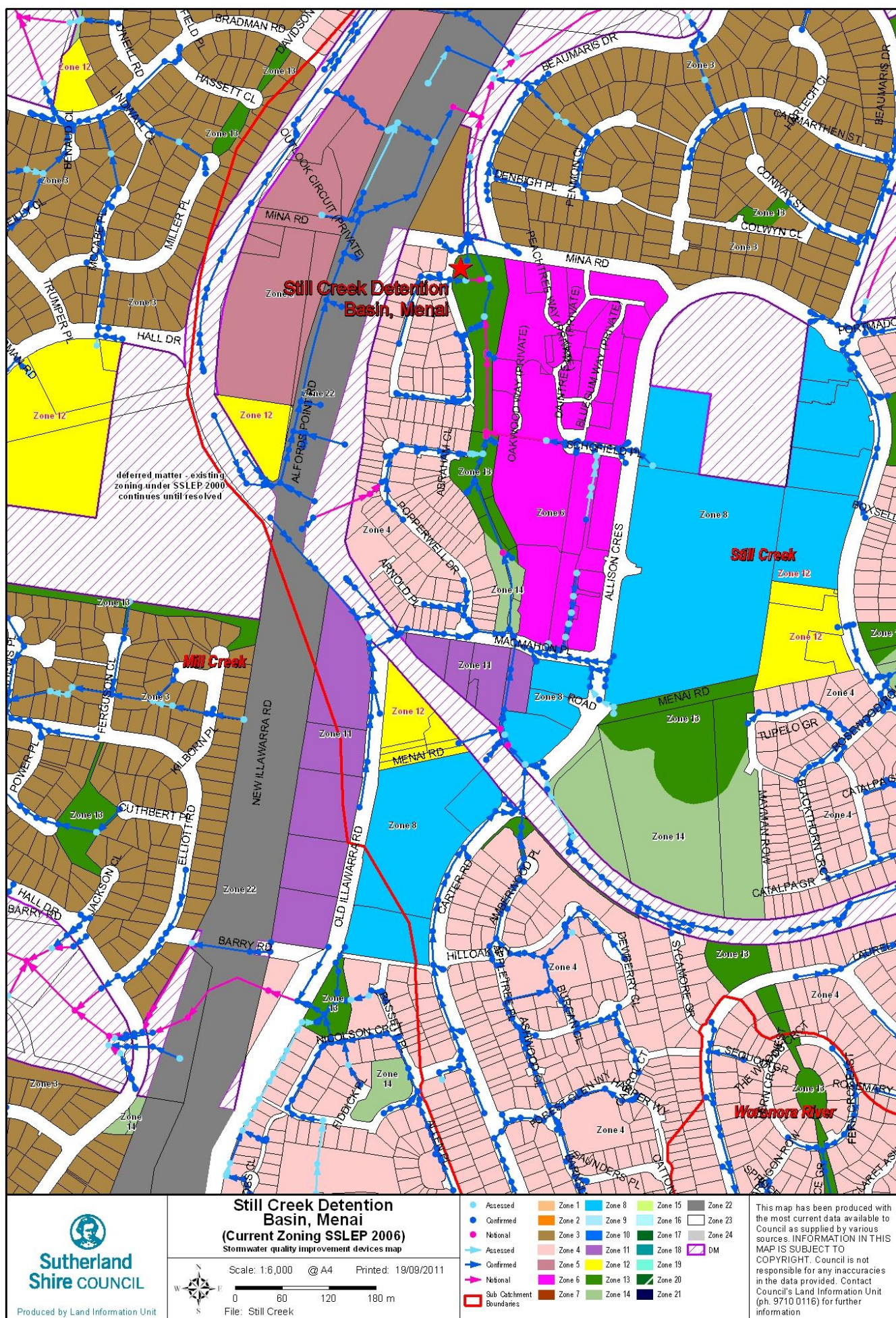
Map 2.23 Still Creek Detention Basin Soil Types.





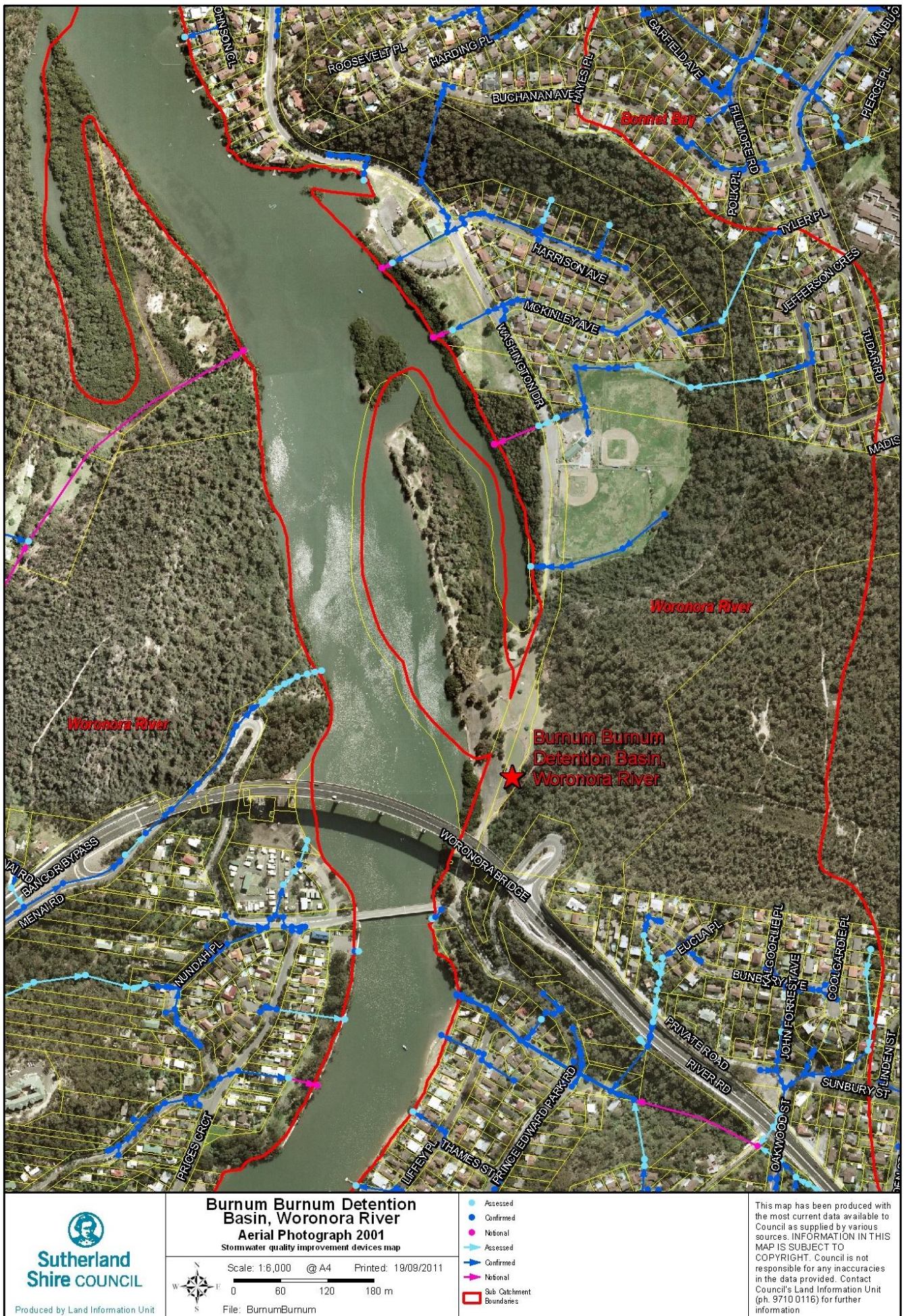
Map 2.24 Still Creek Detention Basin Past Zoning SSLEP 2000. Note Appendix 2 for Legend Description.





Map 2.25 Still Creek Detention Basin Current Zoning SSLEP 2006. Note Appendix 3 for Legend Description.



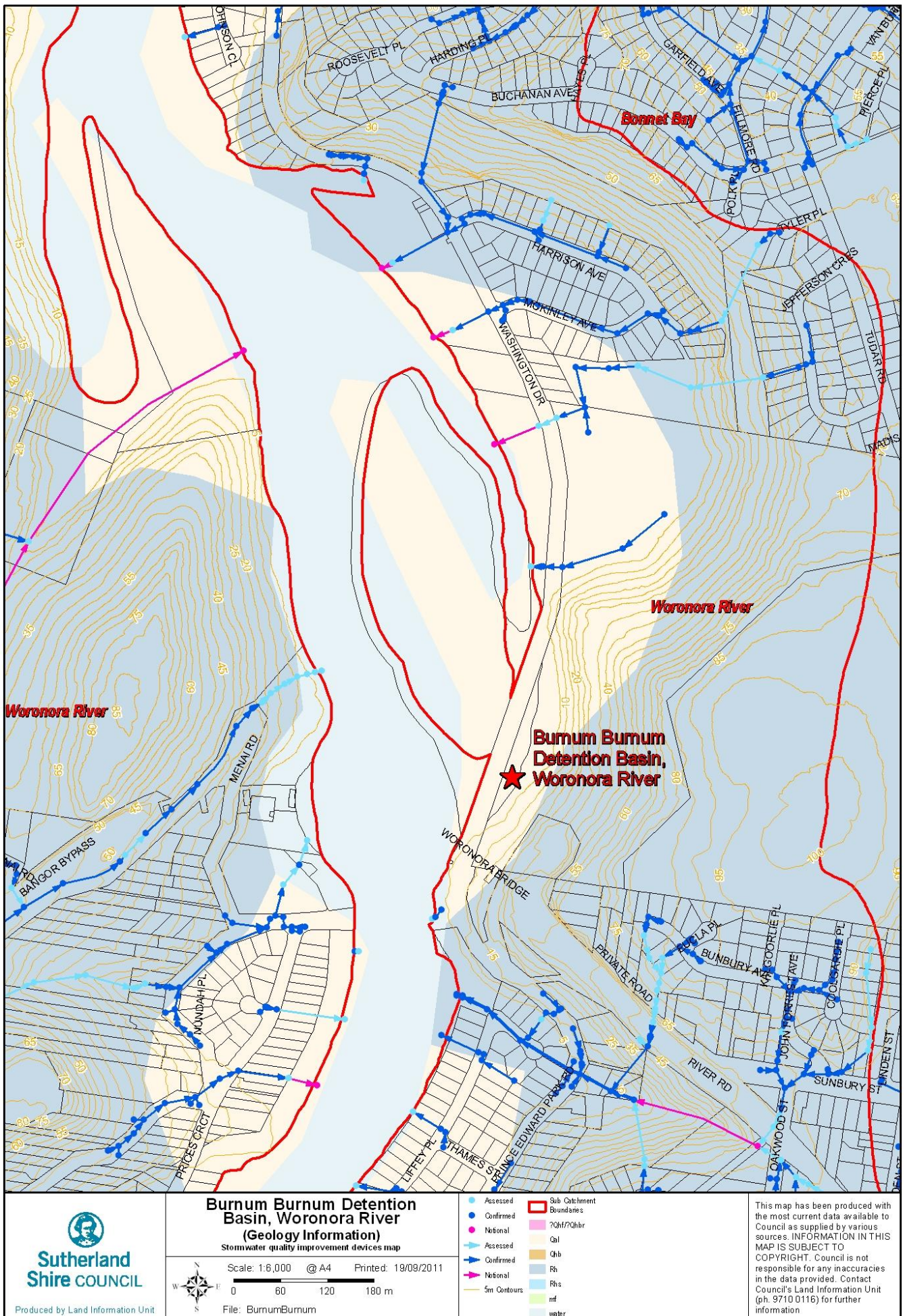


Map 2.26 Burnum Burnum Detention Basin Aerial Photograph 2001.



Map 2.27 Burnum Burnum Detention Basin Aerial Photograph 2010.



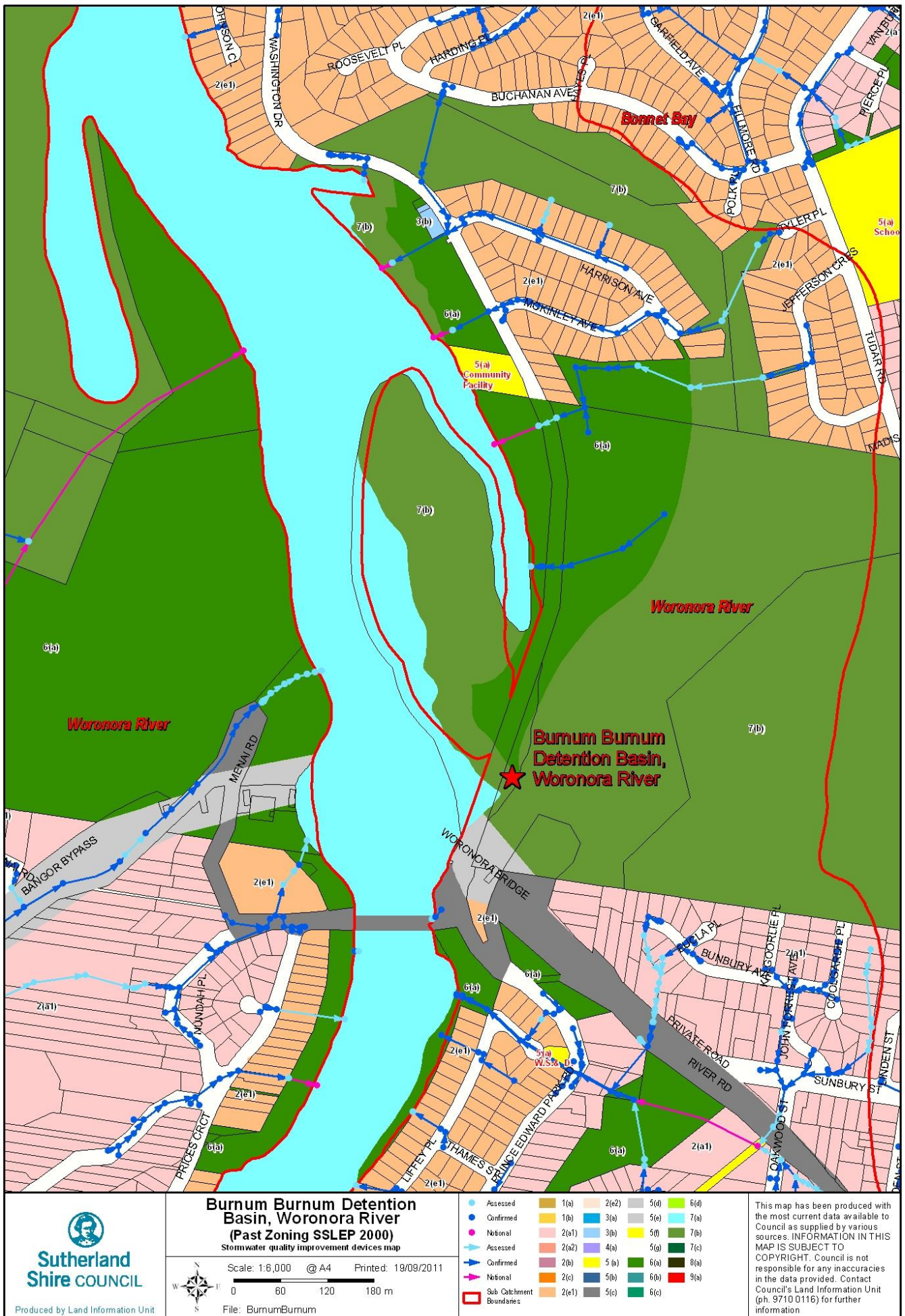


Map 2.28 Burnum Burnum Detention Basin Geology. Note Appendix 1 for Legend Description.



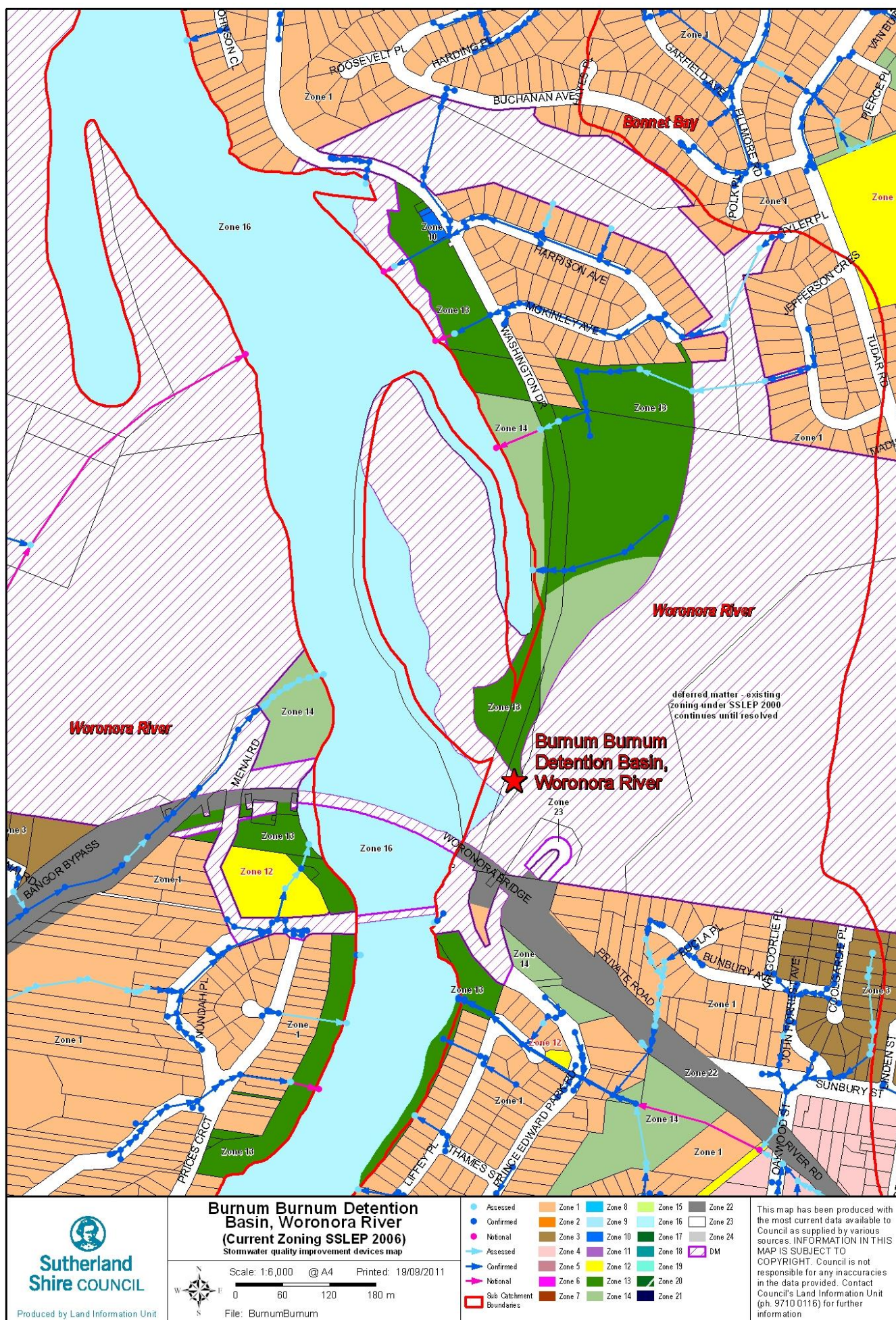






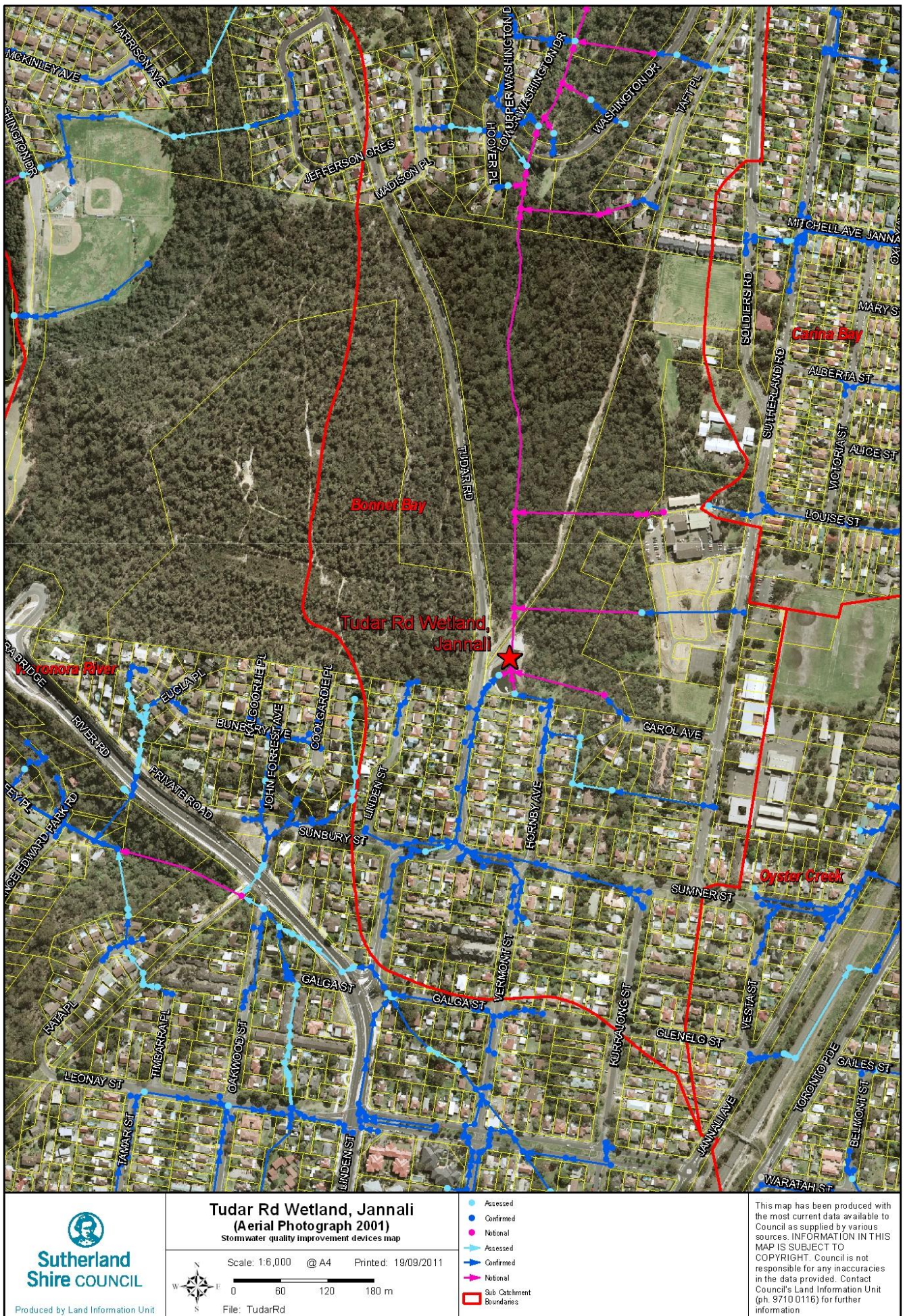
Map 2.30 Burnum Burnum Detention Basin Past Zoning SSLEP 2000. Note Appendix 2 for Legend Description.





Map 2.31 Burnum Burnum Detention Basin Current Zoning SSLEP 2006. Note Appendix 3 for Legend Description.





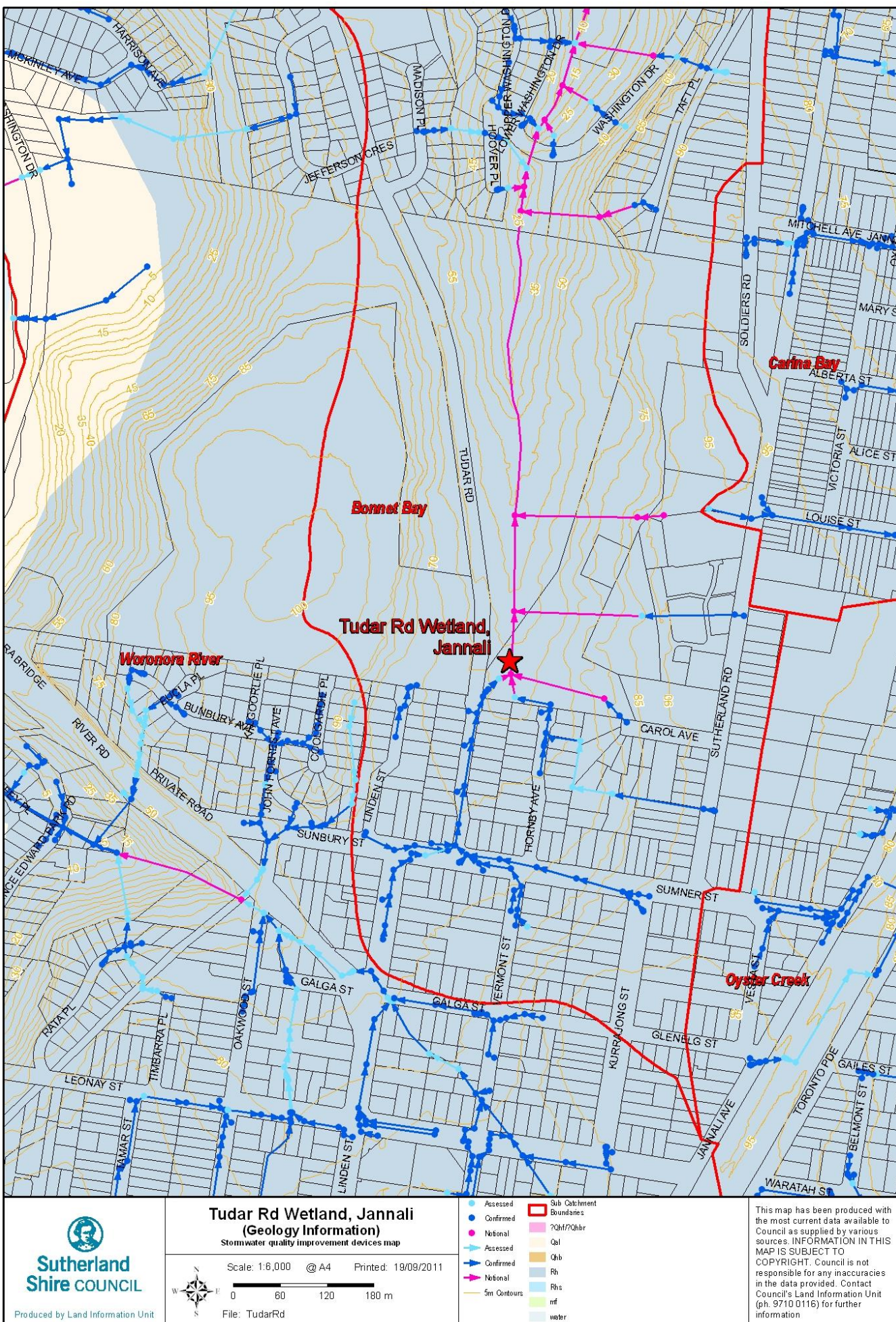
Map 2.32 Tudar Road Wetland Aerial Photograph 2001.





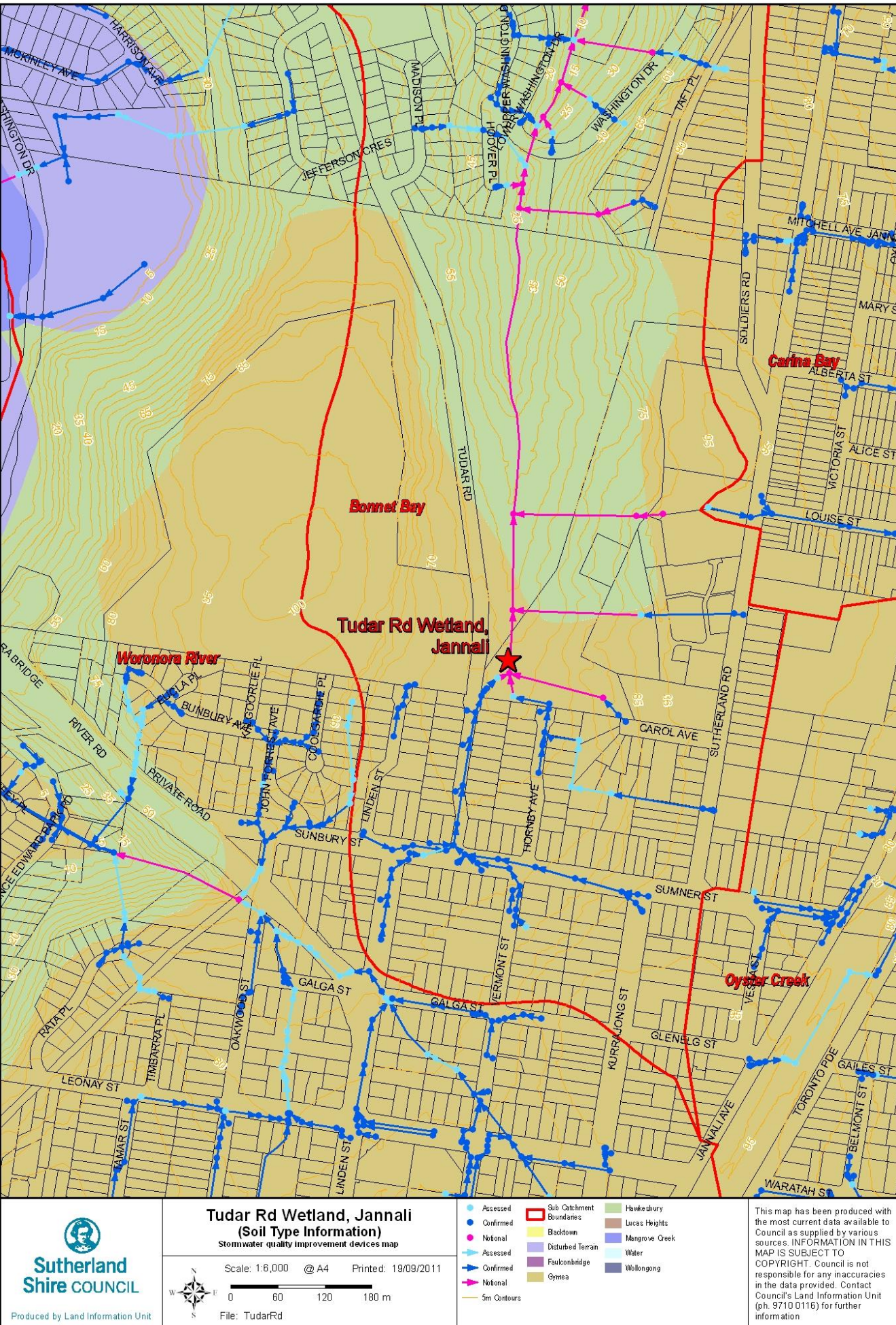
Map 2.33 Tudar Road Wetland Aerial Photograph 2010.





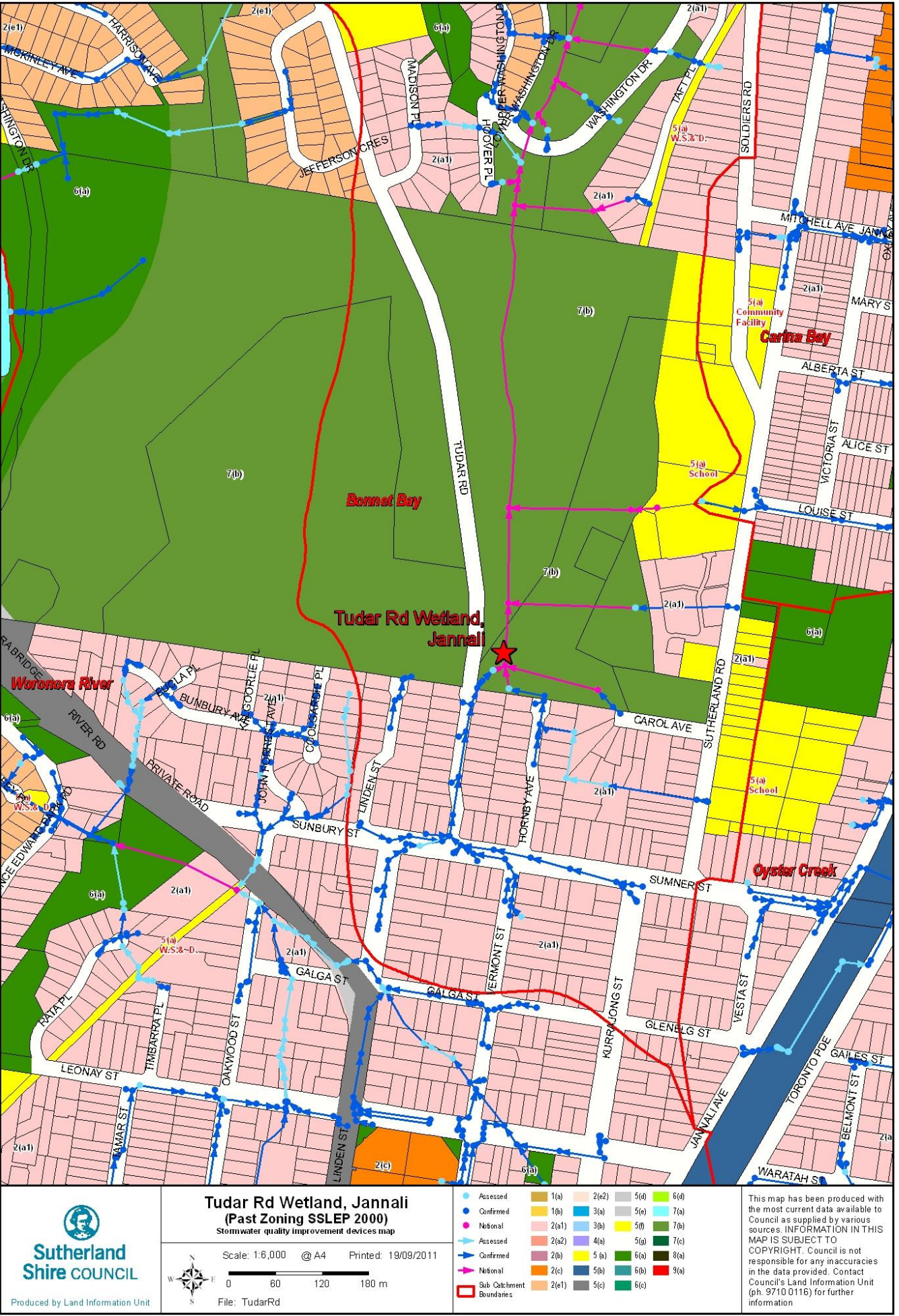
Map 2.34 Tudar Road Wetland Geology. Note Appendix 1 for Legend Description.





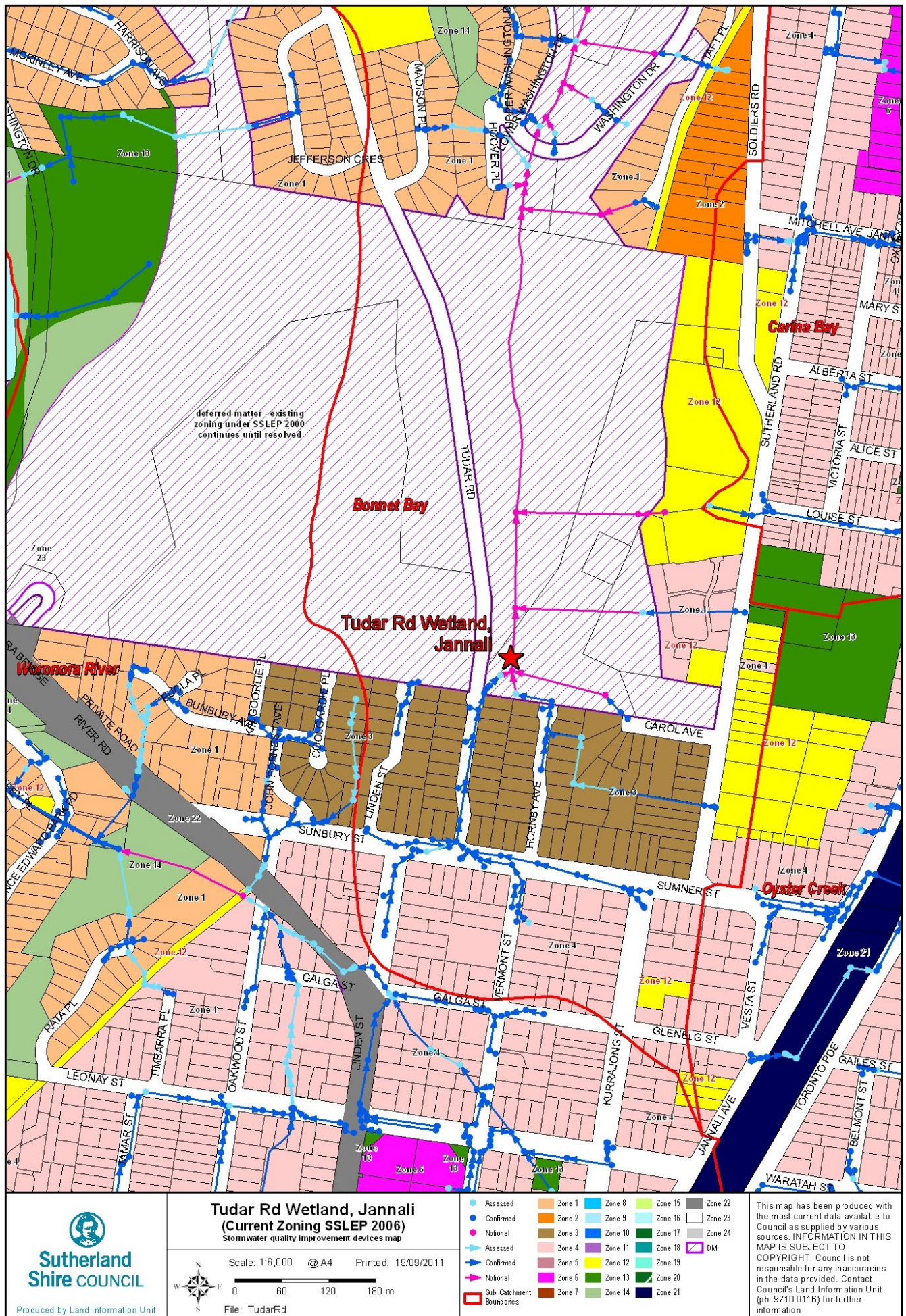
Map 2.35 Tudar Road Wetland Soil Types.





Map 2.36 Tudar Road Wetland Past Zoning SSLEP 2000. Note Appendix 2 for Legend Description.





Map 2.37 Tudar Road Wetland Current Zoning SSLEP 2006. Note Appendix 3 for Legend Description.



## 2.2 Field Sampling Procedures

Sutherland Shire Council contracts ALS Group to collect and analyse water samples from the water quality monitoring sites they are responsible for managing. As such, ALS Group was involved in sampling each of the six SQIDs of interest to this study. The sampling was conducted during the morning on five separate days, these being, 3/2/11, 13/4/11, 11/5/11, 8/6/11 and 28/7/11. Tide was a determining factor in the selection of an appropriate sampling time due to the outlet of Cronulla Beach GPT being inaccessible at all times, except low tide. To retrieve the water samples from the SQIDs a “Mighty Gripper” sampling pole and attached sample collection bottle was used. This method was employed for all but one of the sites, the Gunnamatta Bay GPT inflow, where access to the water surface is restricted by a protective grate. Opening the grate requires the assistance of trained council maintenance staff and as a result, does not always occur. To collect the water samples in this instance, a small pump was used to draw the water from below the grate. This method was used for four of the five sampling dates, these being, 3/2/11, 13/4/11, 11/5/11 and 28/7/11. Before sampling the pump was cleaned using the water to be sampled by letting the water run through uncollected for one to two minutes. To prepare the collection bottle and prevent cross-contamination the bottle was first cleaned using Earth Choice Multi-Purpose Cleaner and rinsed with de-ionised and reverse osmosis treated water. Following this, the bottle was then rinsed 2-3 times using the water to be analysed. Only after following this procedure were the samples then taken. To collect the samples the bottle was positioned 10-20cm below the surface of the water to avoid disturbing bottom sediment and prevent any floating objects from entering the bottle. The collected water was then transferred to the designated sampling bottle. ALS Group contractors collected six different water samples for the purpose of analysing different water quality parameters. The first to be collected was a 125 mL sample with no preservation for *Enterococci* analysis. Following this a 125 mL sample with nitric acid preservation was collected for total metals analysis. Two 250 mL samples with sulphuric acid preservation were then taken to measure ammonia, TKN, total nitrogen and total phosphorus. An additional 250 mL sample was taken with no preservation treatment for BOD determination and finally a 1 L sample was taken for nitrate, nitrite and suspended solids analysis. These samples were then stored on ice to chill them to 4°C and transported to ALS Group laboratories for analysis. Identical sampling was completed for both the inlet and outlet of each SQID in order to compare the relative differences in water quality after having passed through the treatment system.



In addition to these water samples, standard water quality parameters were recorded using a Water Quality Meter 90FLMSVK. This device measured electrical conductivity, pH, temperature and dissolved oxygen (DO) whilst in the field. Due to a pump being used to access the water at the Gunnamatta Bay GPT inflow, the DO values for this site could be unrealistically elevated for the four sampling events which employed the pumping approach. The pump was not utilised for the fourth sampling event as in this instance the grate needed to be opened to allow sediment collection. Sediment samples were taken from each SQUID inlet and outlet location on the fourth sampling day in order to conduct grainsize analysis. It was not deemed necessary to complete the sediment collection for each of the five sampling days, due to the limited fluctuation in representative sediment sizes which are likely to be encountered in this kind of situation. Sediment was collected using a sampling pole and attached bottle which was used to scoop some material from the subaqueous surface and then deliver it to a sample bag. In some instances the sediment was of such a fine grade that it could not be satisfactorily separated on site from the water. If this occurred the contents of the sample bottle was transferred to a 1 L sample bottle and sealed for later analysis. Prior to and following sediment collection, the sampling pole and attached bottle was cleaned using the water present on site.

## 2.3 Laboratory Methods

ALS Group employed a variety of methods in the analysis of the water samples collected. Detailed procedural instructions can be found for all of the methods employed by ALS, except for the *Enterococci* analysis, in *Standard Methods for the Examination of Water and Wastewater 21<sup>st</sup> Edition* (APHA, 2005). The APHA reference, for each method, is provided below, along with a description of the procedures utilised.

In order to determine suspended solids a gravimetric procedure was employed which examines the ‘non-filterable’ residue from a water sample (APHA 21<sup>st</sup> ed., 2540 D). To achieve this, a glass-fibre filter (1.2  $\mu\text{m}$ ) is prepared by rinsing with deionised water, after which it is oven dried and weighed. The weighed filter is then used to collect the residue from the water sample and this residue is then dried at  $104\pm 2^\circ\text{C}$ . After a second weighing the increase in weight can be attributed to the suspended solids in the water sample analysed (APHA, 2005).



To determine the concentrations of the various metals the Inductively Coupled Plasma Mass Spectrometry (ICPMS) method was utilised (APHA 21<sup>st</sup> ed., 3125). This technique employs the use of a high temperature argon plasma, into which the sample is introduced (APHA, 2005). This causes the metals to be ionised, allowing the ions to be extracted from the plasma and moved into a high vacuum mass spectrometer where they are separated according to their mass-to-charge ratios. They are then measured using a discrete dynode ion detector.

To analyse the ammonia concentration, direct colourimetry was used (APHA, 21<sup>st</sup> ed., 4500-NH<sub>3</sub> G). This involves treating the sample with alkaline phenol and hypochlorite which react with the ammonia to form indophenol blue (APHA, 2005). The formation of indophenol blue is proportional to the ammonia concentration and the blue colour formed can be intensified with the addition of sodium nitroprusside (APHA, 2005). Colourimetry by Discrete Analyser is then used to determine the ammonia concentration.

The concentration of nitrite and nitrate was determined by Cadmium Reduction and direct colourimetry (APHA 21<sup>st</sup> ed., 4500-NO<sub>3</sub> F). Nitrate is reduced almost quantitatively to nitrite in the presence of cadmium which is added to the sample in the form of cadmium granules, treated with copper sulphate (APHA, 2005). A highly coloured azo dye is then formed by adding sulfanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride which can be measured using colourimetry (APHA, 2005), in this case by Discrete Analyser.

Total Kjeldahl Nitrogen (APHA 21<sup>st</sup> ed., 4500-N<sub>org</sub> D) was determined by first digesting 25 mL of sample using a traditional Kjeldahl digestion, which involves using a block digester with sulphuric acid and copper sulfate as a catalyst (APHA, 2005). The digestion process recovers nitrogen of biological origin, although it does not recover nitrate. The digested sample is then processed by Discrete Analyser to determine the Kjeldahl nitrogen concentration.

Total Nitrogen was determined through the combination of the previous two methods whereby its concentration is essentially TKN plus the combined concentration of nitrite and nitrate (APHA 21<sup>st</sup> ed., 4500-N<sub>org</sub> D/ 4500-NO<sub>3</sub> F).



To determine the concentration of total phosphorus a 100 mL sample is taken and sulfuric acid digestion is used to break the phosphorous down to orthophosphate (APHA 21<sup>st</sup> ed., 4500-P B&F). The addition of ammonium molybdate and antimony potassium tartrate causes the orthophosphate to react, forming antimony-phosphomolybdate complex (APHA, 2005). This complex is then reduced with ascorbic acid to produce an intense blue colour which is measured photometrically at 880 nm by Discrete Analyser.

To measure Biochemical Oxygen Demand (BOD) the 5-Day BOD test was utilised (APHA 21<sup>st</sup> ed., 5210 B). This method involves diluting a sample into oxygenated, nutrient rich water and then a seed is added to promote biological decay. Following this sample preparation, the dissolved oxygen concentration is measured and the bottle sealed and incubated in darkness at  $20\pm1^{\circ}\text{C}$  for five days. It is necessary to store the sample in darkness to prevent any possible photosynthetic production of oxygen (APHA, 2005). After five days the remaining dissolved oxygen is measured and the difference between it and the initial measurement allows the oxygen demand to be determined.

Finally, the enumeration of *Enterococci* was achieved by use of a membrane filtration technique whereby samples are plated onto agar which contains triphenyl tetrazolium chloride as a marker substance and sodium azide as a selective agent (Domig et al., 2003). The plate is then incubated for 48-72 hrs at  $37^{\circ}\text{C}$  after which time the *Enterococci* appear as pink or dark red-brownish colonies.

In addition to the laboratory analysis conducted by ALS Group, grain size analysis was undertaken at the University of Wollongong using a Malvern Mastersizer 2000. This procedure involved first preparing the Mastersizer by measuring background levels using a clean 1 L tap water sample. The sediment sample was then prepared for analysis by placing a small amount of sediment within a 1 L container of water. The prepared sample was then introduced to the Mastersizer and diluted until the sediment concentration was within a measurable range. Following this, ultrasonic treatment was applied to the sample to break down any aggregates that may have existed. As a result of this, the sample may have moved above the measurable range once more, therefore demanding correction by diluting the sample once again to reduce the sediment concentration. The Mastersizer analysis procedure could then be run giving a total of three separate readings with an average of all these readings taken at the end. If the analysis was considered unsatisfactory, due to the variation



between the readings being too large, the analysis sequence was run again to see if the result could be improved. Often, a more acceptable result was produced the second or third time, however, if this failed an averaged result was taken, from the collection of averages produced, and that measure was used.

Due to the fact that the Mastersizer cannot accommodate larger sediment grades ( $>2$  mm), six of the eleven samples were sieved prior to being added to the 1 L container of tap water. To achieve this, the sediment sample was first weighed to give a total weight and then following sieving, the collected coarse sediment fraction was weighed. The coarse sediment was then placed in an oven and left for 4 days to dry out while the finer sediment was analysed immediately using the Mastersizer. After four days the dried sediment was taken and sieved once again to determine the different sediment sizes present. The weights of each sediment size category were recorded and these data were combined with the total sample weight and total coarse sediment weight recorded four days previously. This information was then analysed using Excel to produce laser size analysis graphs for each site examined.



### 3. Results

#### 3.1 Water Quality Analysis

The water quality analysis conducted, revealed differences in the water composition entering the six SQIDs and the condition of the resultant outflow. In most cases the results produced were what was expected, that is the inflow concentrations were higher than the outflow concentrations, although for some parameters at certain sites, this was not what was observed. It should be noted that those results which were below the LOR, and have been included in the graphing, appear as a value of 0 on the curve. The results for the four wetland systems will be reported first followed by the two GPT only systems. Note that Tables 3.1 to 3.6 present the water quality data in association with the guideline values and rainfall information, which will be discussed further in Chapter 4.

##### 3.1.1 Mianga Avenue Wetland

The field parameters for Mianga Avenue Wetland (Table 3.1) showed that temperature (Fig. 3.4) was slightly higher at the inflow when compared to the outflow, although on 13/4/2011 the values were largely unchanged. A steady decrease in temperature across the inflow and outflow was observed over the course of the sampling period. Electrical conductivity (Fig 3.2) was significantly higher at the inflow across all sampling events. The pH curve (Fig. 3.1), while showing an apparent correlation between the inflow and the outflow, with a fall in one being matched by a fall in the other, does not clearly display whether the pH at one point is characteristically higher than the other or not. The graphs for dissolved oxygen (Fig. 3.3) and suspended solids (Fig. 3.5) are also somewhat ambiguous, with the outflow showing a lower measure than the inflow on all occasions except 13/4/2011. Unfortunately, no inflow data was available for the 3/2/2011 due to inaccessibility on the day and therefore a comparison cannot be made. In terms of the metals, arsenic was below the LOR for both inflow and outflow on all days sampled. This was also the case for cadmium (Fig. 3.6), chromium (Fig. 3.7) and nickel (Fig. 3.9) although cadmium showed an increased measure at the outflow on 13/4/2011 while chromium experienced an elevated reading at the inflow on 28/7/2011 and nickel elevated readings at the inflow on 8/6/2011 and 28/7/2011. Copper (Fig. 3.8) and zinc (Fig. 3.11) were detected above the LOR, although all outflow measurements were either equal to or below the inflow. Interestingly, the inflow curves for these two metals, along with lead (Fig. 3.10), were similar, though zinc displayed less



dramatic changes. Lead conveyed a particularly ambiguous result where the inflow and outflow appear to have little correlation at all. This was also the case for ammonia (Fig. 3.12) and TKN (Fig. 3.14). Nitrite and nitrate (Fig. 3.13), total nitrogen (Fig. 3.15) and total phosphorus (Fig. 3.16) all display visible correlations between the inflow and the outflow with the outflow showing a reduction in the targeted parameters. This is particularly so for nitrite and nitrate which appears to maintain a consistently low outflow reading despite a dramatic increase in inflow concentration. *Enterococci* (Fig. 3.18) and BOD (Fig. 3.17) also follow this pattern where the outflow maintains a consistently low result despite very high inflow concentrations on 13/4/2011 and 8/6/2011, in the case of *Enterococci*, and on 8/6/2011 only, in the case of BOD.

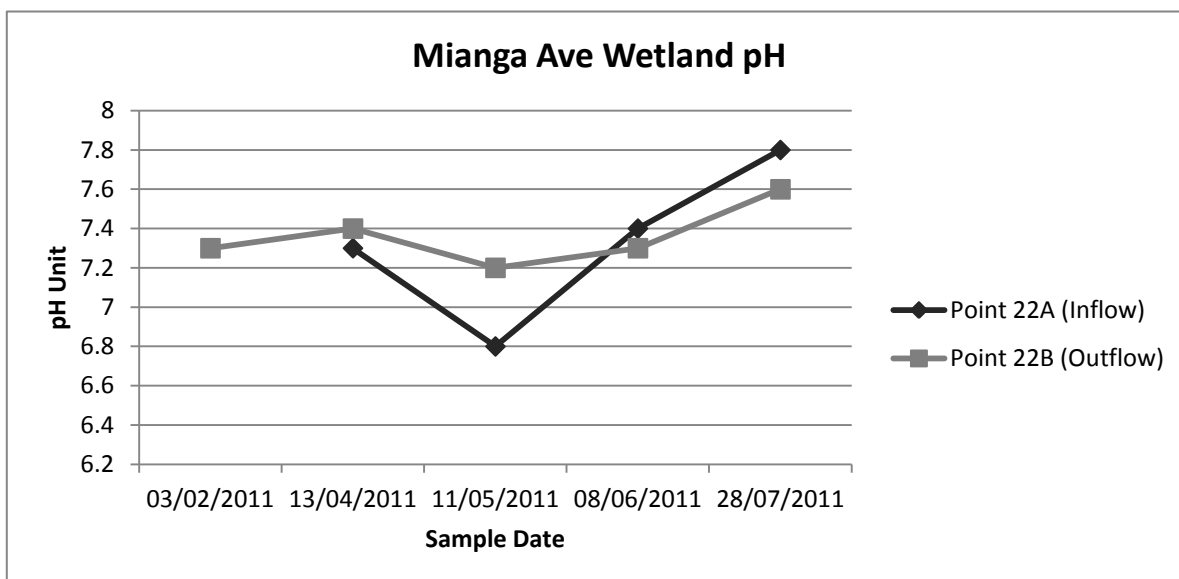


Figure 3.1 Mianga Avenue Wetland pH (LOR = 0.1).

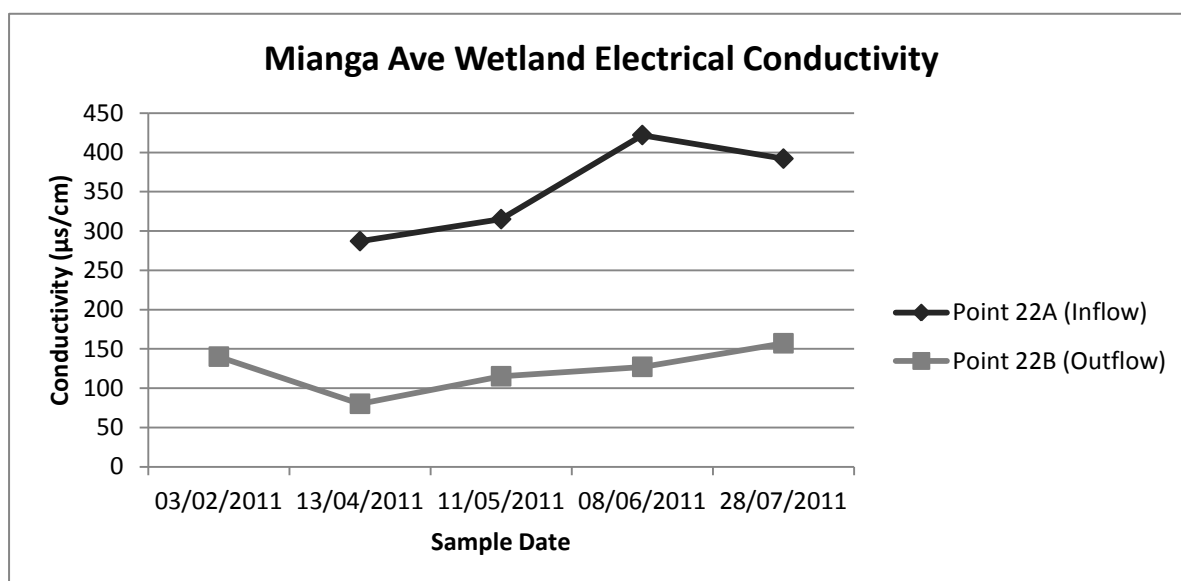


Figure 3.2 Mianga Avenue Wetland Electrical Conductivity (LOR = 1).



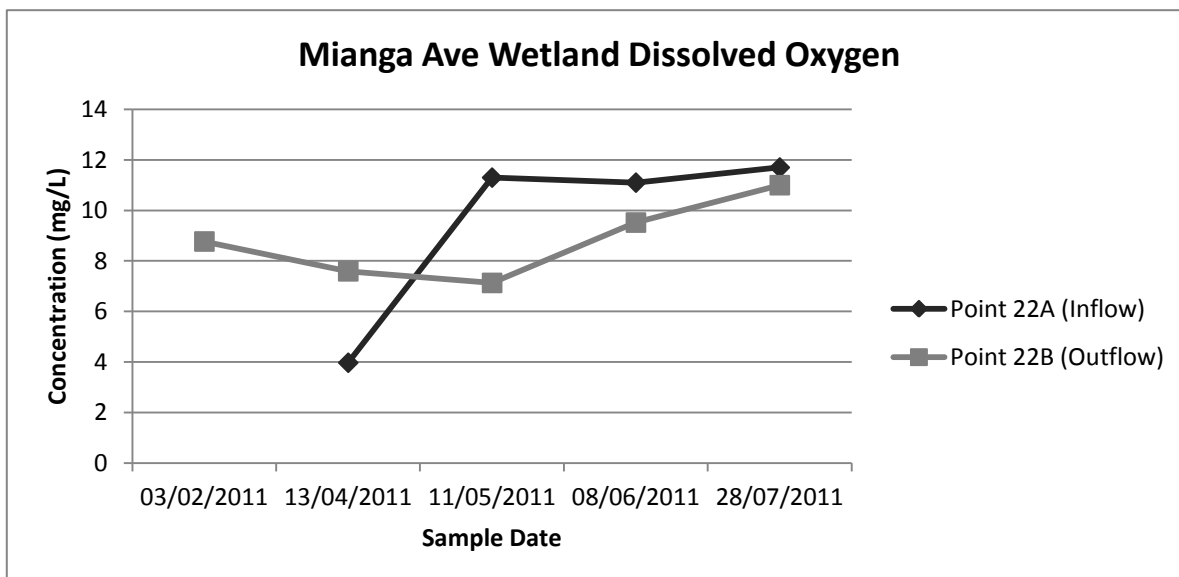


Figure 3.3 Mianga Avenue Wetland Dissolved Oxygen (LOR = 0.01).

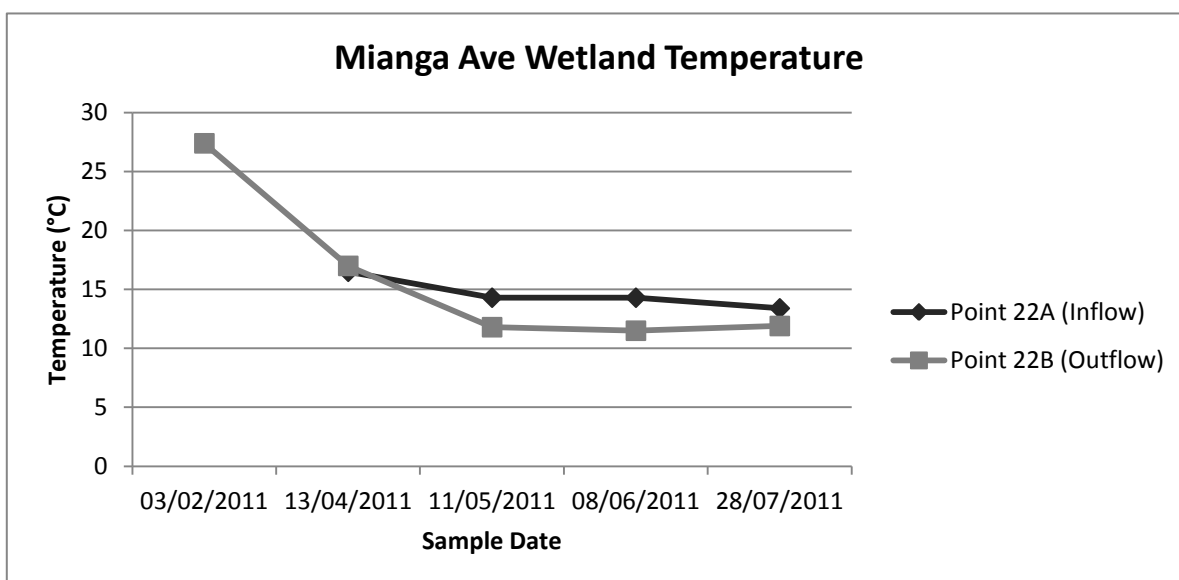


Figure 3.4 Mianga Avenue Wetland Temperature (LOR = 0.1).

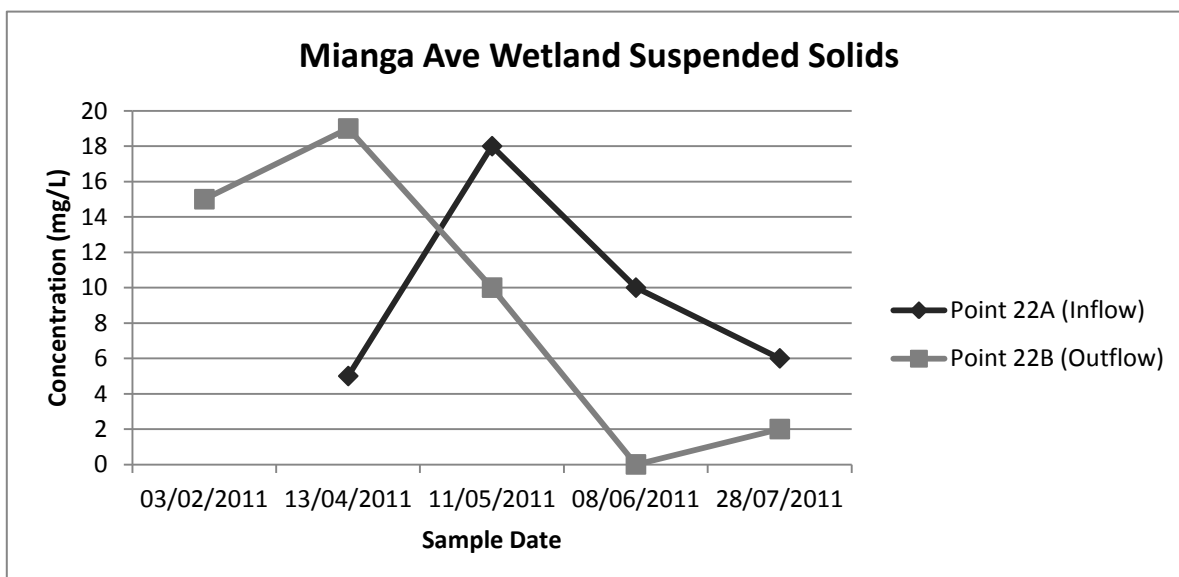


Figure 3.5 Mianga Avenue Wetland Suspended Solids (LOR = 1).



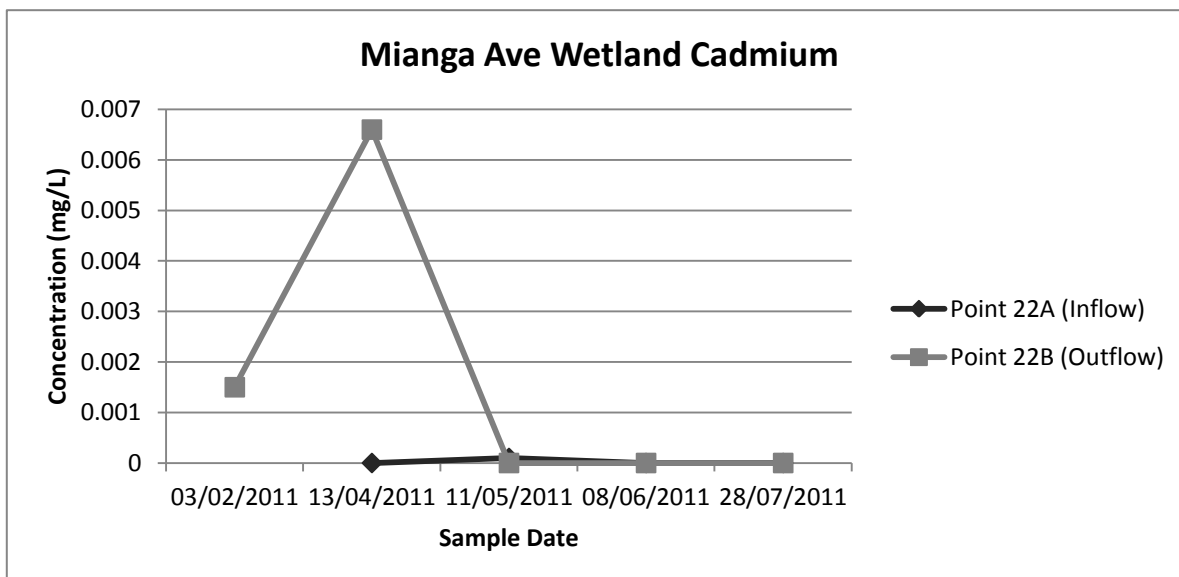


Figure 3.6 Mianga Avenue Wetland Cadmium (LOR = 0.0001).

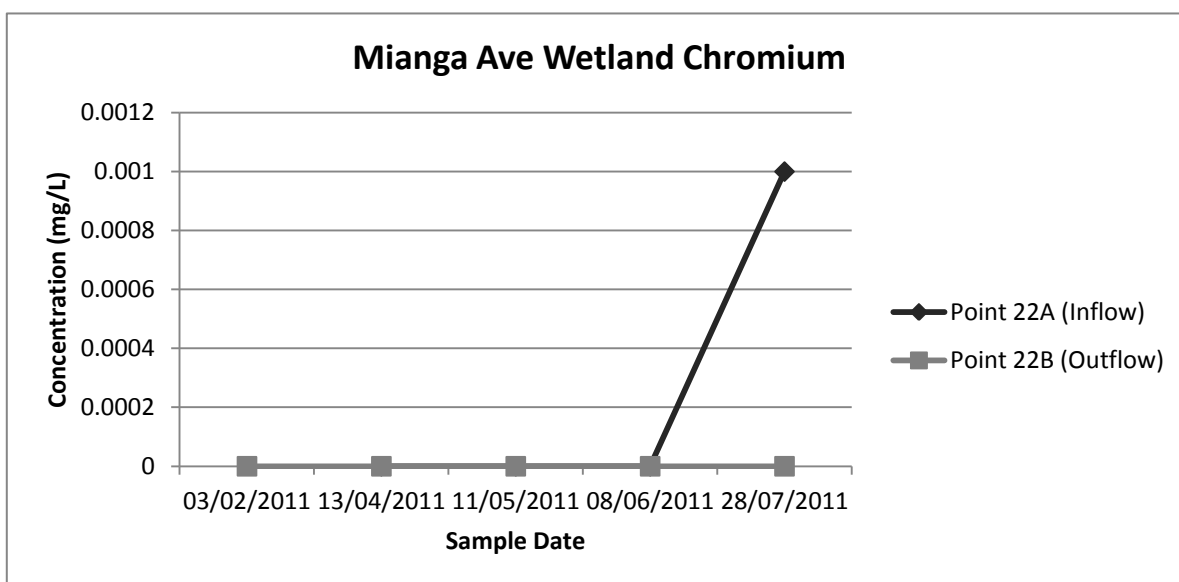


Figure 3.7 Mianga Avenue Wetland Chromium (LOR = 0.001).

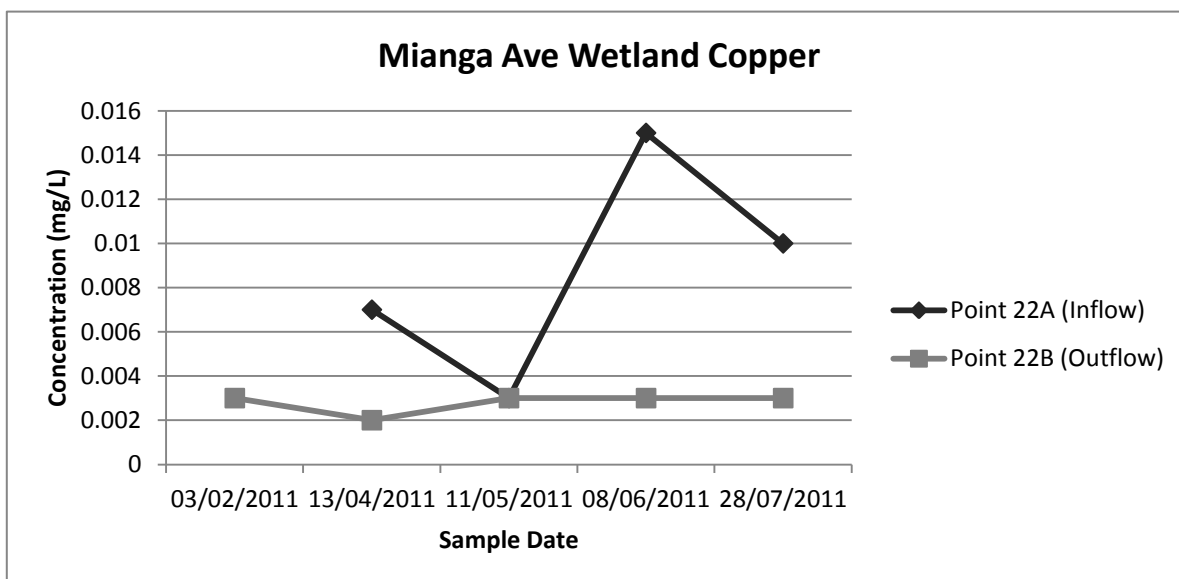


Figure 3.8 Mianga Avenue Wetland Copper (LOR = 0.001).



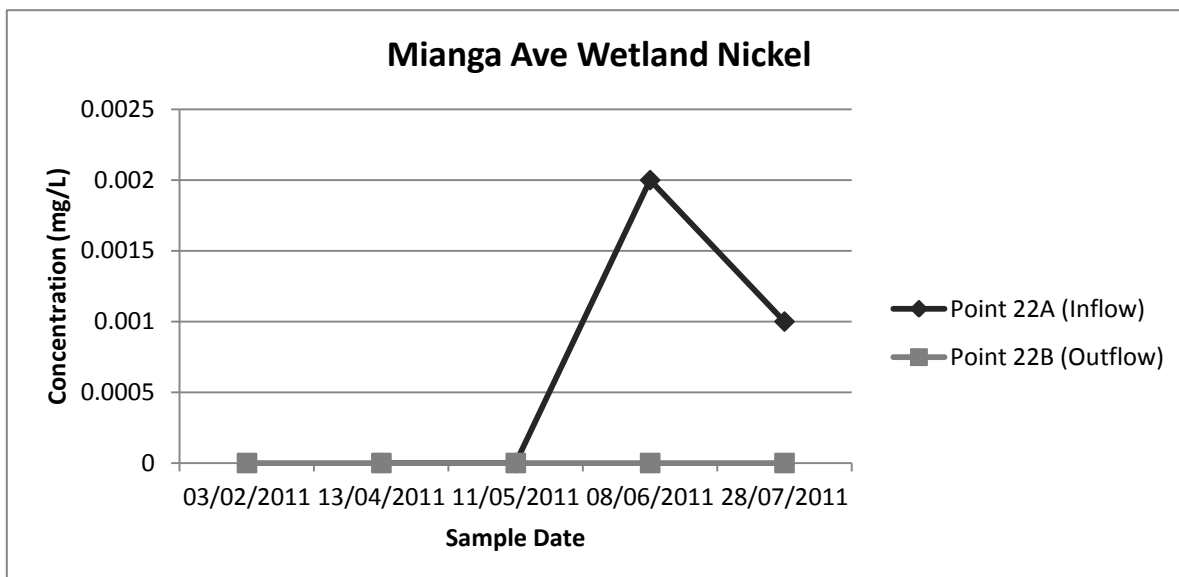


Figure 3.9 Mianga Avenue Wetland Nickel (LOR = 0.001).

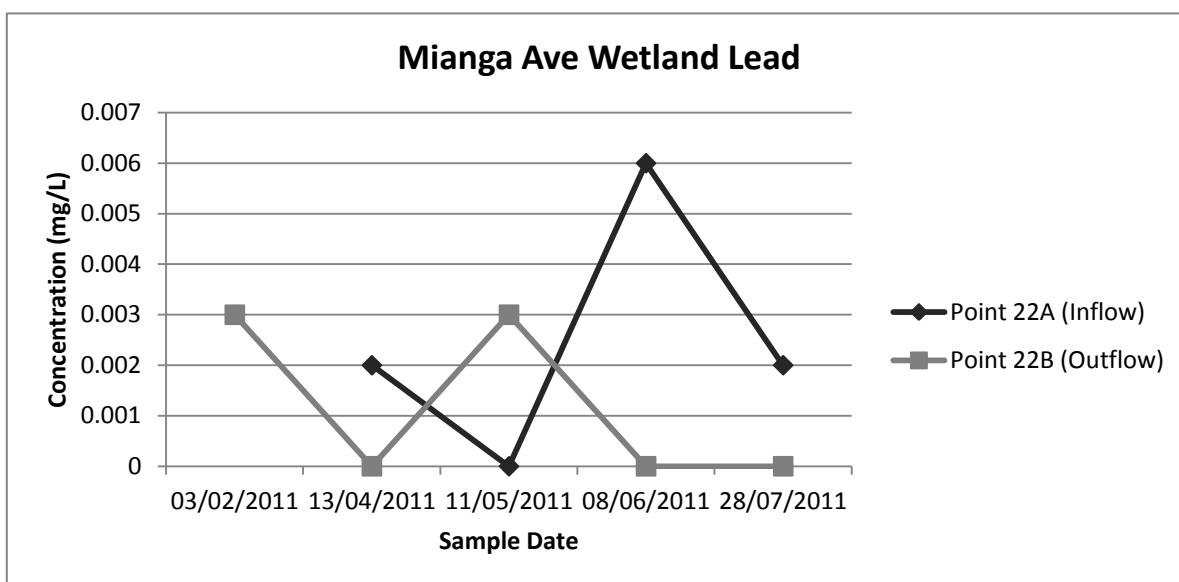


Figure 3.10 Mianga Avenue Wetland Lead (LOR = 0.001).

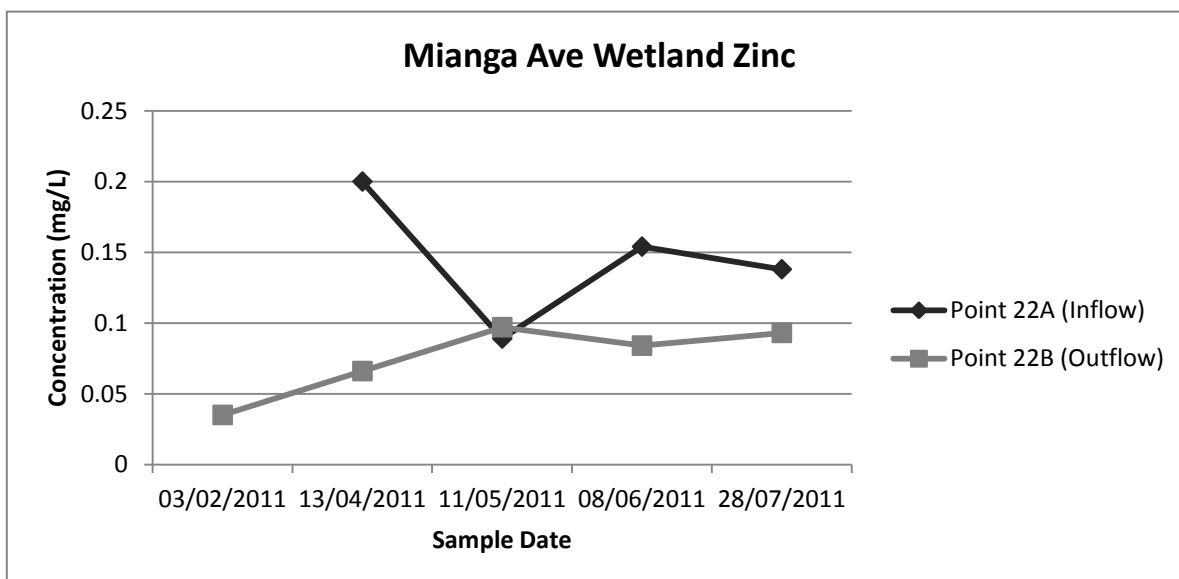


Figure 3.11 Mianga Avenue Wetland Zinc (LOR = 0.005).



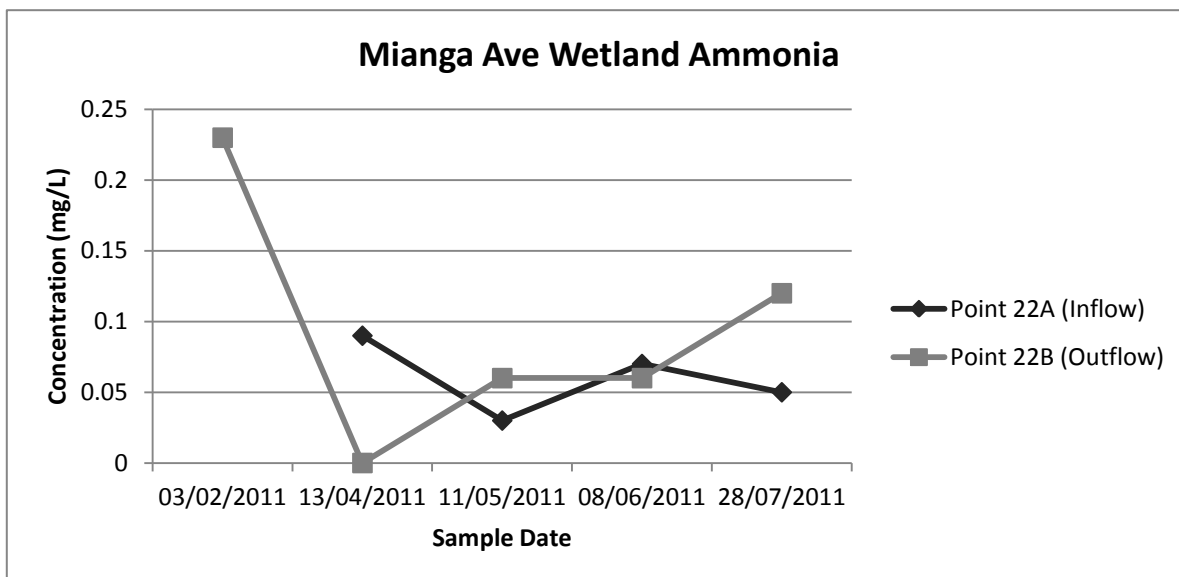


Figure 3.12 Mianga Avenue Wetland Ammonia (LOR = 0.01).

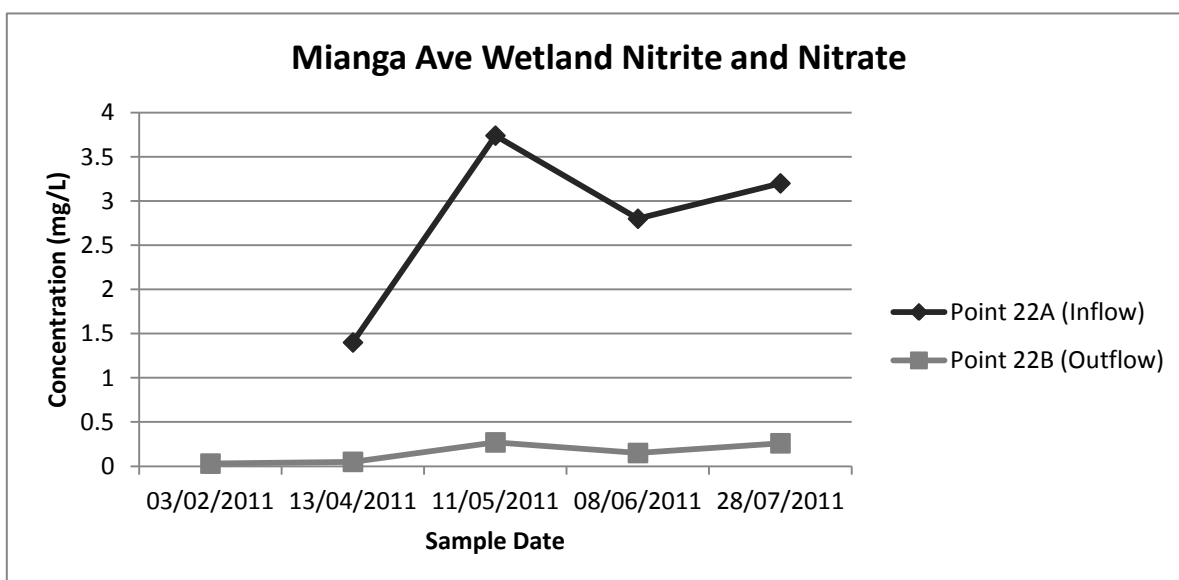


Figure 3.13 Mianga Avenue Wetland Nitrite and Nitrate (LOR = 0.01).

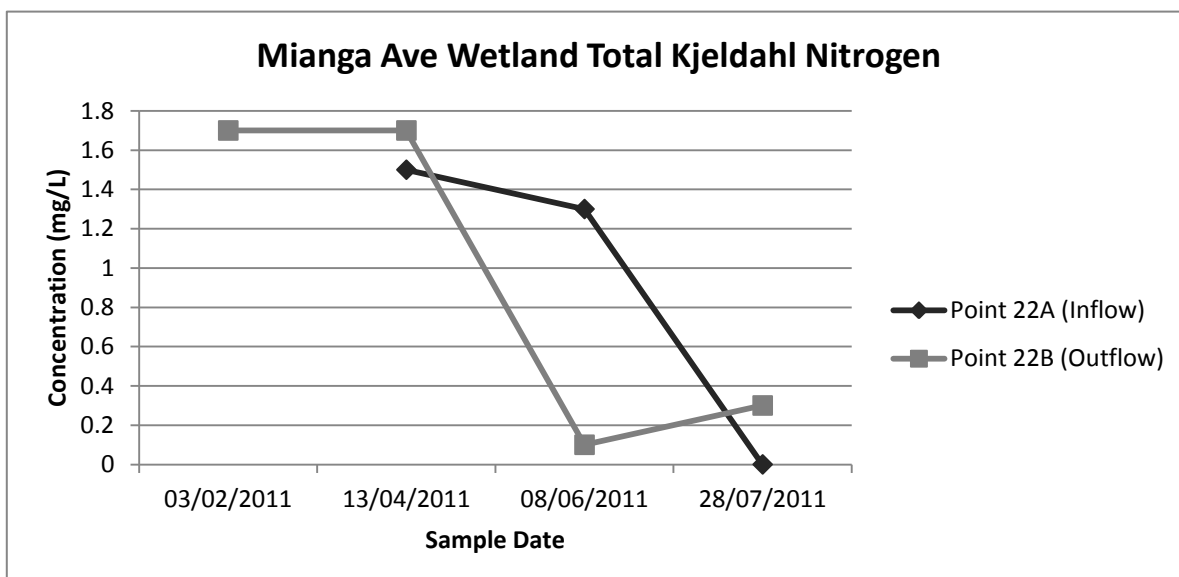


Figure 3.14 Mianga Avenue Wetland Total Kjeldahl Nitrogen (LOR = 0.1).



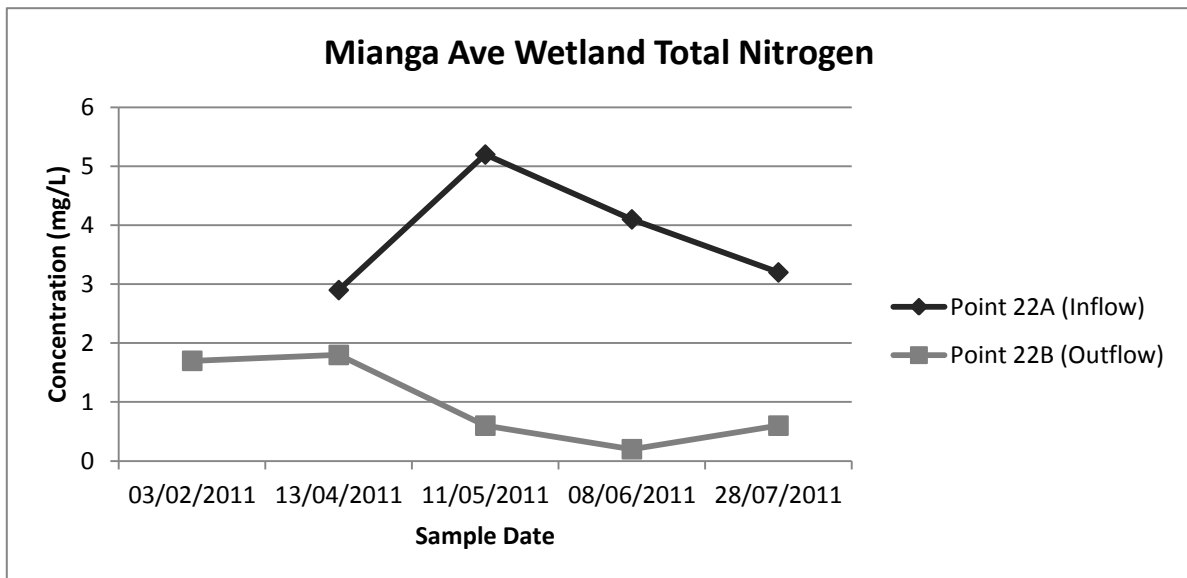


Figure 3.15 Mianga Avenue Wetland Total Nitrogen (LOR = 0.1).

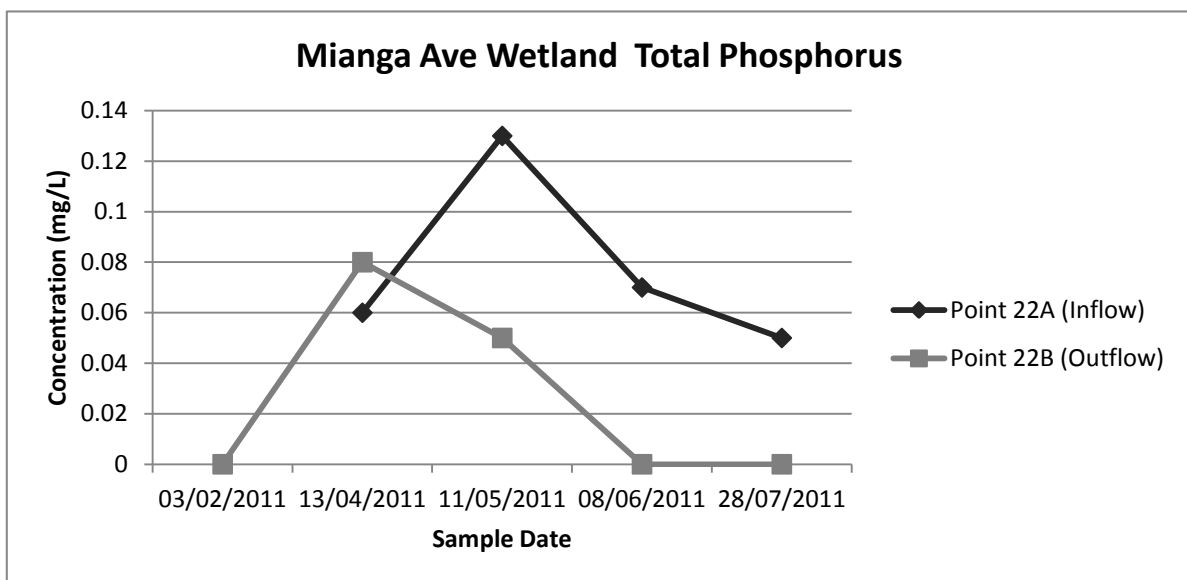


Figure 3.16 Mianga Avenue Wetland Total Phosphorus (LOR = 0.01).

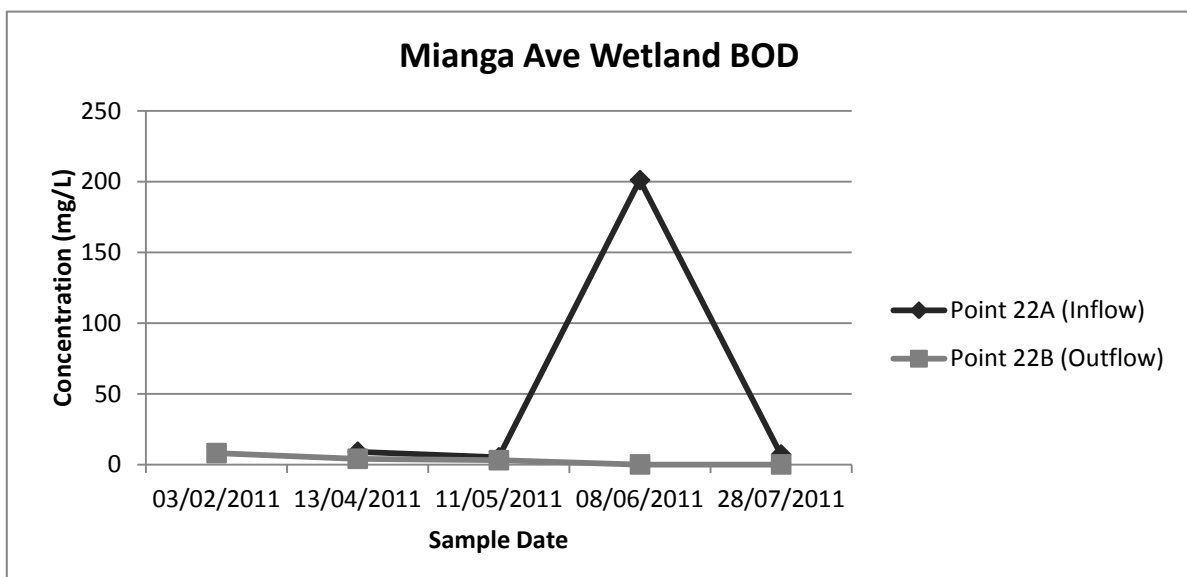


Figure 3.17 Mianga Avenue Wetland BOD (LOR = 2).



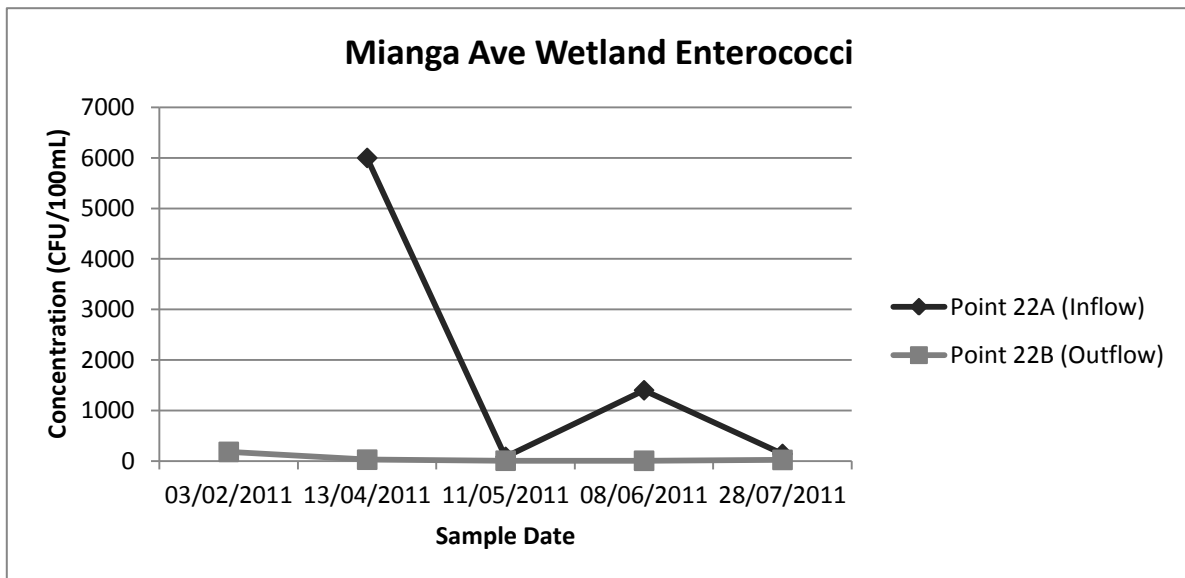


Figure 3.18 Mianga Avenue Wetland *Enterococci* (LOR = 1).

### 3.1.2 Tudar Road Wetland

The field parameters for Tudar Road Wetland (Table 3.2), electrical conductivity (Fig. 3.20), temperature (Fig. 3.22) and dissolved oxygen (Fig. 3.21), all show clear associations between the inflow and the outflow, although dissolved oxygen deviates from this relationship between 3/2/2011 and 13/4/2011. pH (Fig. 3.19) does not appear to show any clear association at all whereby lowering of the pH at the inflow was recorded as a raising of the pH at the outflow on 11/5/2011. The inflow and outflow values for suspended solids (Fig. 3.23), arsenic (Fig. 3.24), cadmium (Fig. 3.25), chromium (Fig. 3.26), copper (Fig. 3.27), nickel (Fig. 3.28) and lead (Fig. 3.29) were all below or very close to the LOR with the exception of the sampling conducted on 11/5/2011. This date corresponds with a sharp increase in all of the above parameters creating the easily recognisable pyramid-like graphs. Furthermore, zinc (Fig. 3.30), ammonia (Fig. 3.31), total nitrogen (Fig. 3.34), total phosphorus (Fig. 3.35), BOD (Fig. 3.36) and *Enterococci* (Fig. 3.37) all formed a pyramid graph, although in these instances not as many of the bottom values were equal to or as close to the LOR. Nitrite and nitrate (Fig. 3.32), and TKN (Fig. 3.33) did not display the pyramid shape discussed above. Unfortunately, due to undetermined reasons, no TKN value was supplied from ALS for 11/5/2011. This limits the comparability of this graph to the others, however it can be seen that the inflow value is higher than or equal to the outflow over the period sampled. With regard to the nitrite and nitrate curve, consistently low values were produced for the outflow with the exception of the last sampling event on 28/7/2011. This was achieved despite increases in the inflow values over the same period.

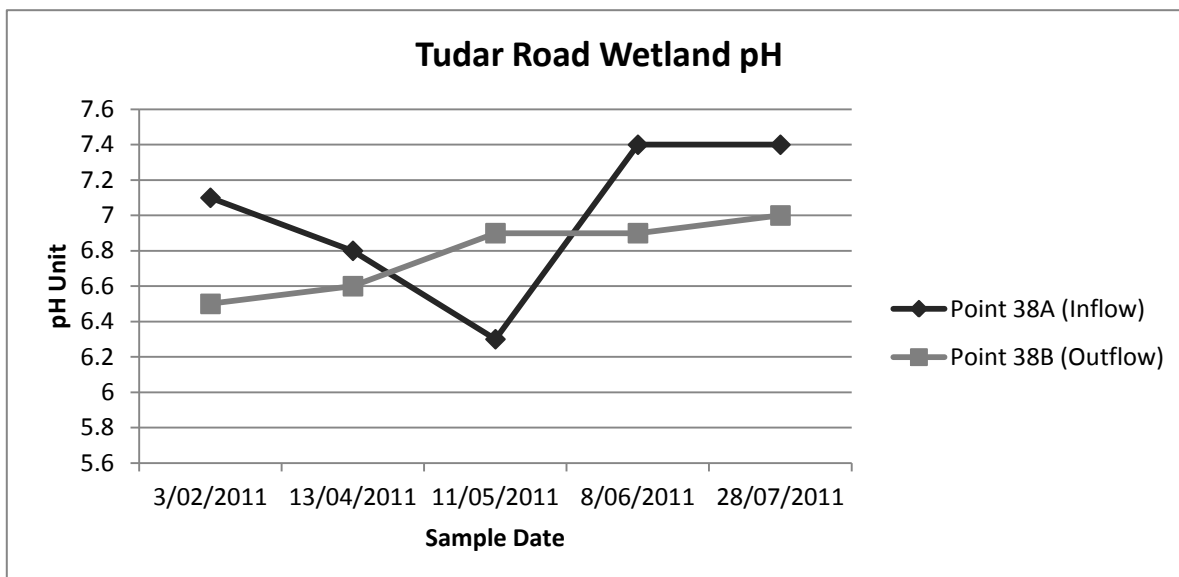


Figure 3.19 Tudor Road Wetland pH (LOR = 0.1).

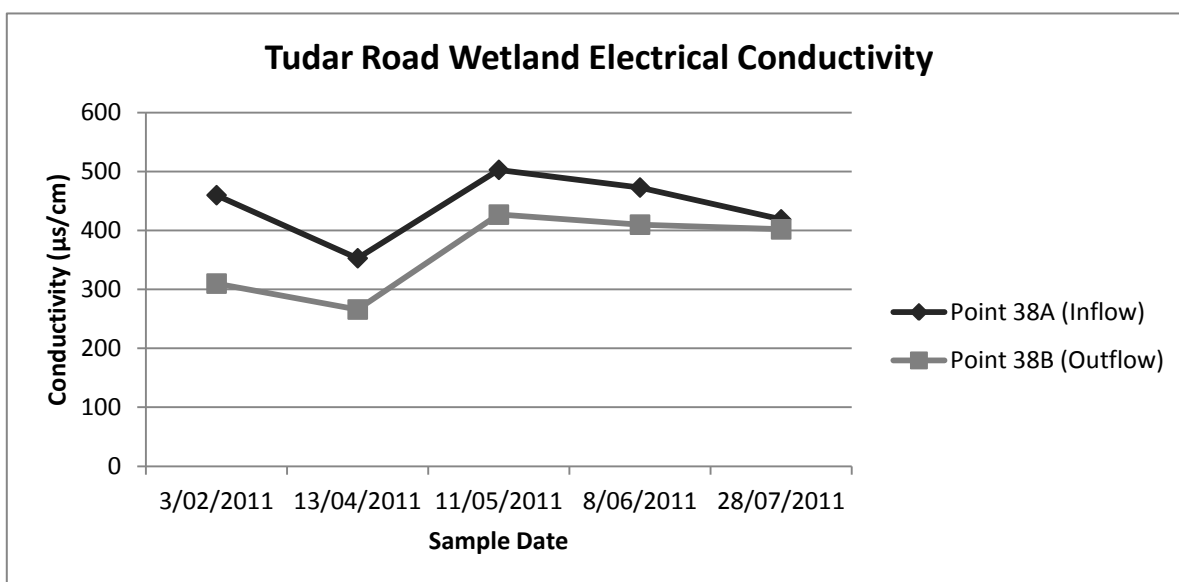


Figure 3.20 Tudor Road Wetland Electrical Conductivity (LOR = 1).

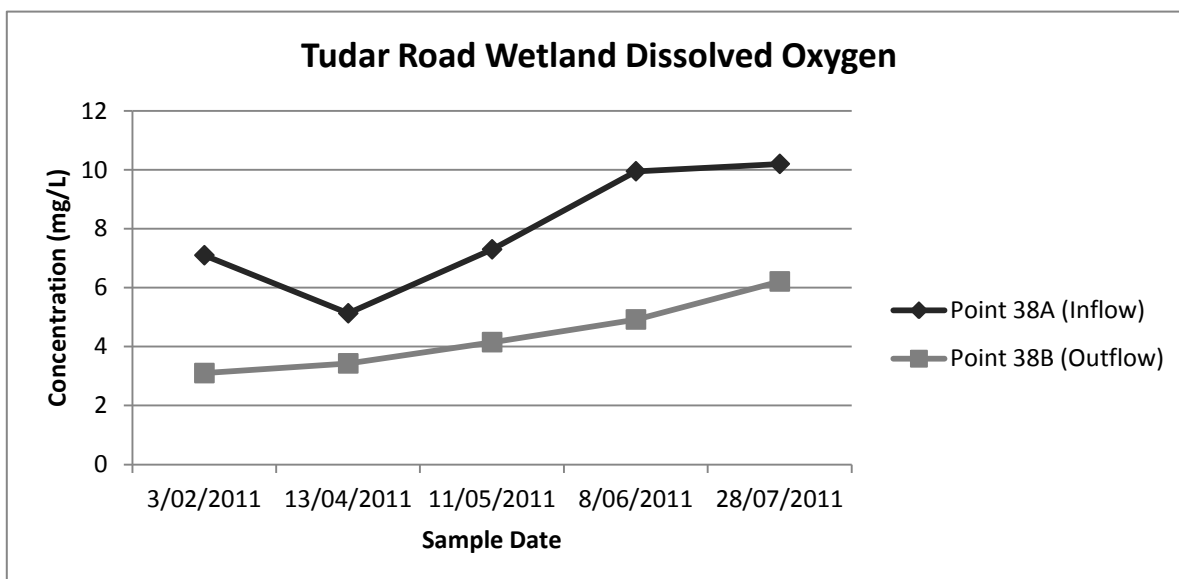


Figure 3.21 Tudor Road Wetland Dissolved Oxygen (LOR = 0.01).



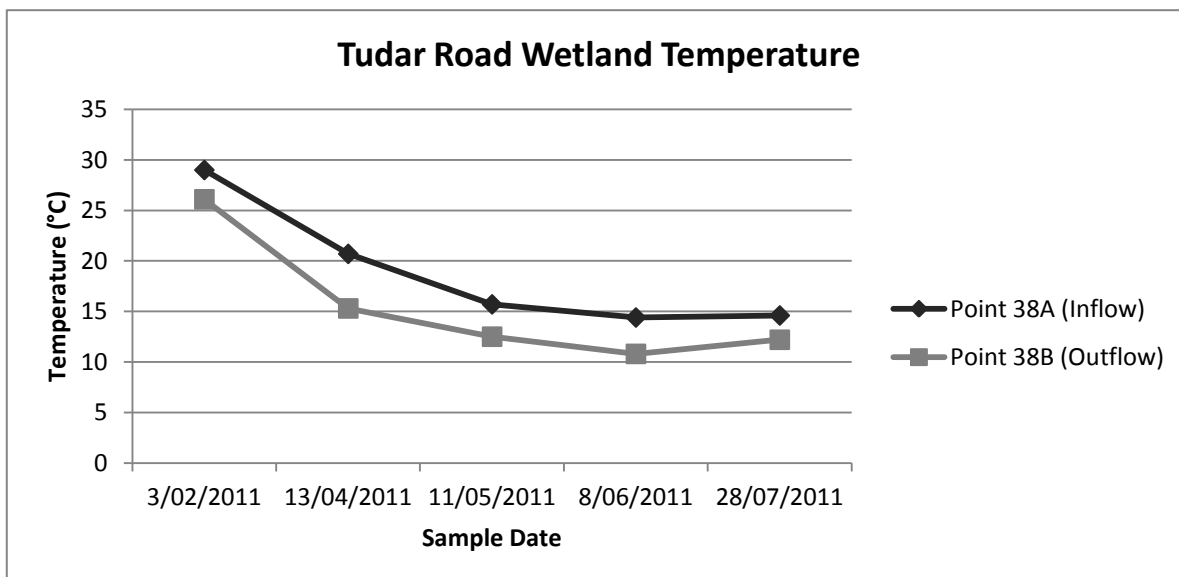


Figure 3.22 Tudor Road Wetland Temperature (LOR = 0.1).

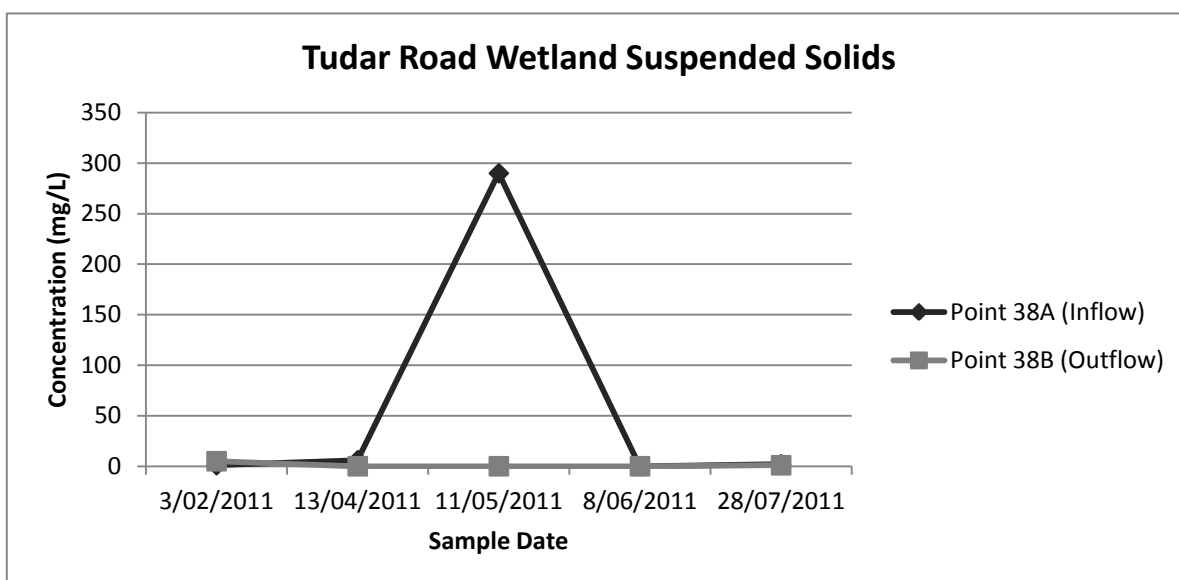


Figure 3.23 Tudor Road Wetland Suspended Solids (LOR = 1).

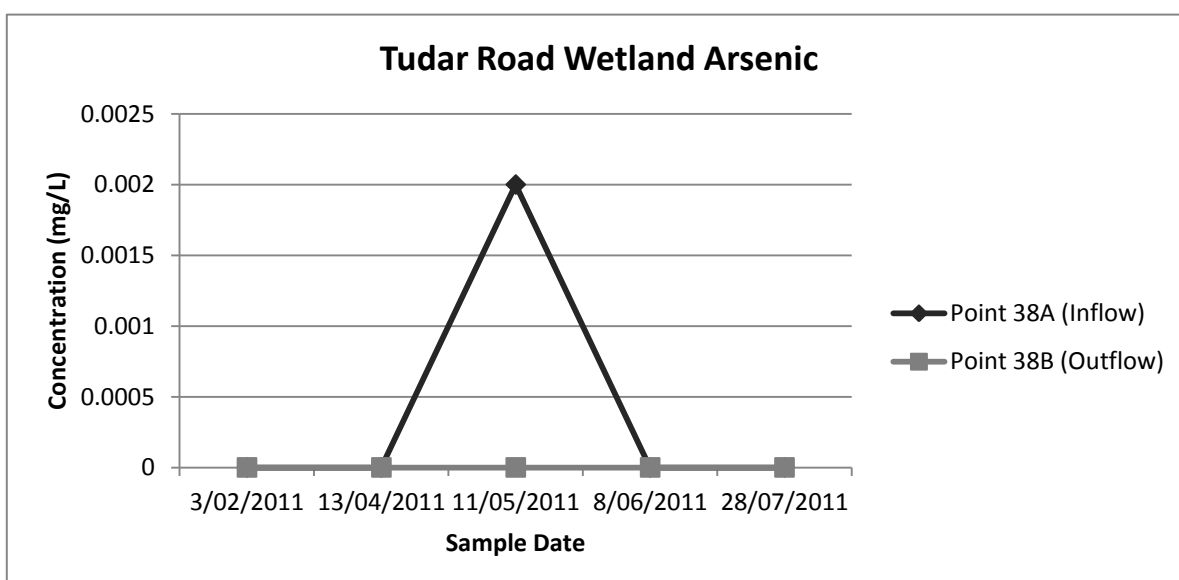


Figure 3.24 Tudor Road Wetland Arsenic (LOR = 0.001).

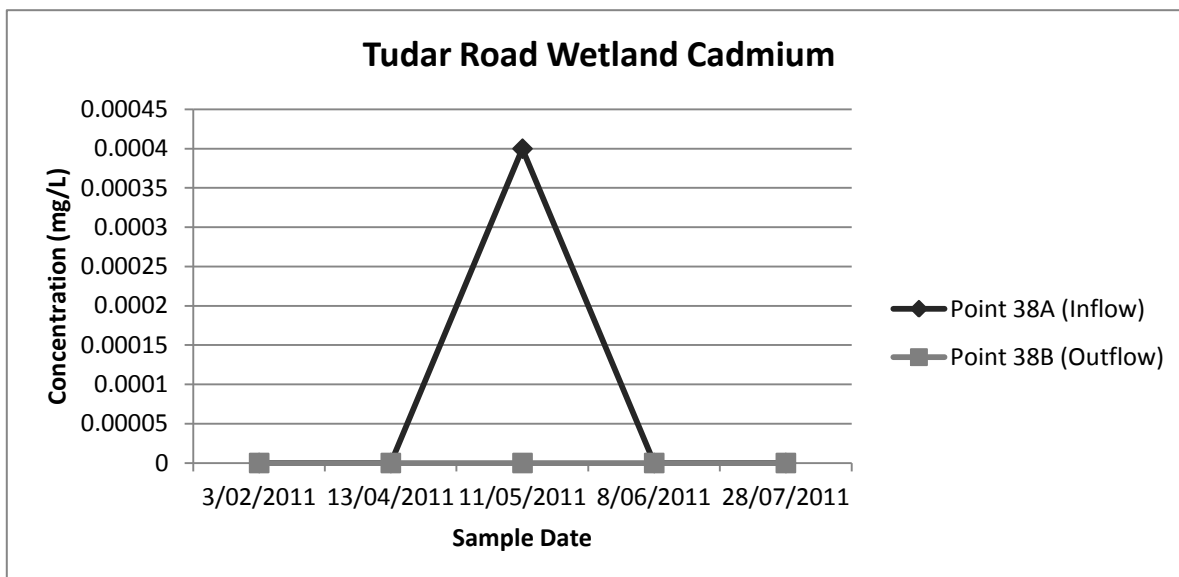


Figure 3.25 Tudor Road Wetland Cadmium (LOR = 0.0001).

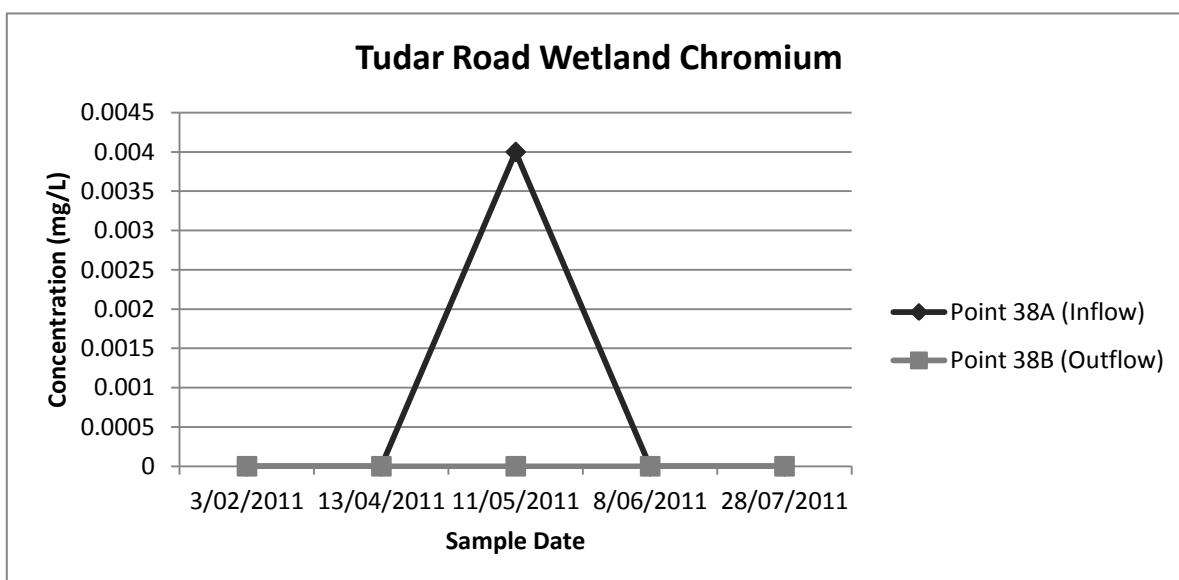


Figure 3.26 Tudor Road Wetland Chromium (LOR = 0.001).

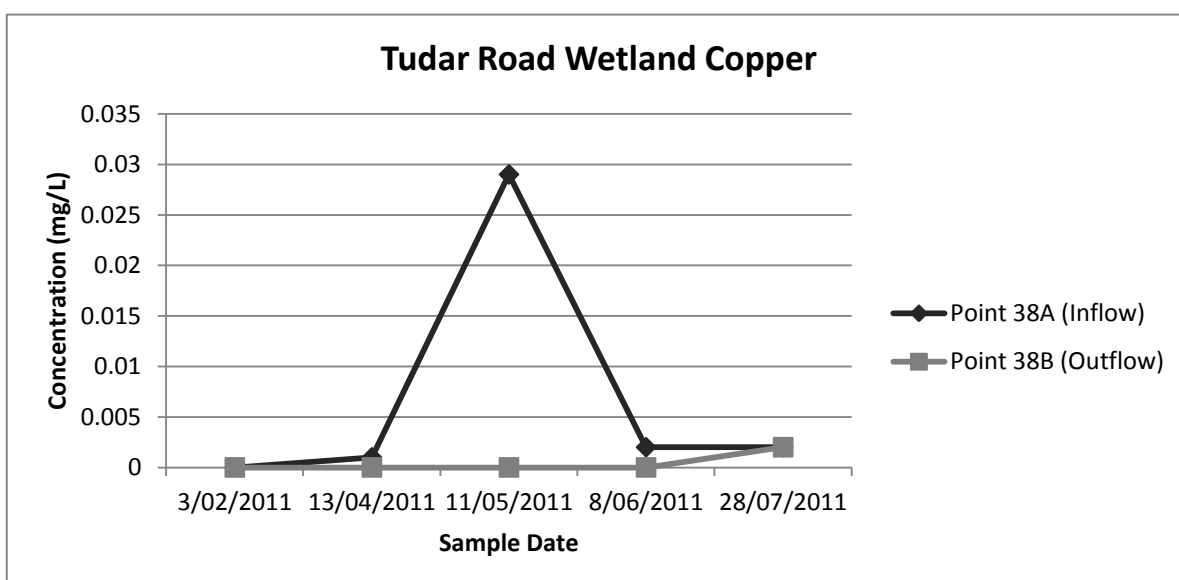


Figure 3.27 Tudor Road Wetland Copper (LOR = 0.001).



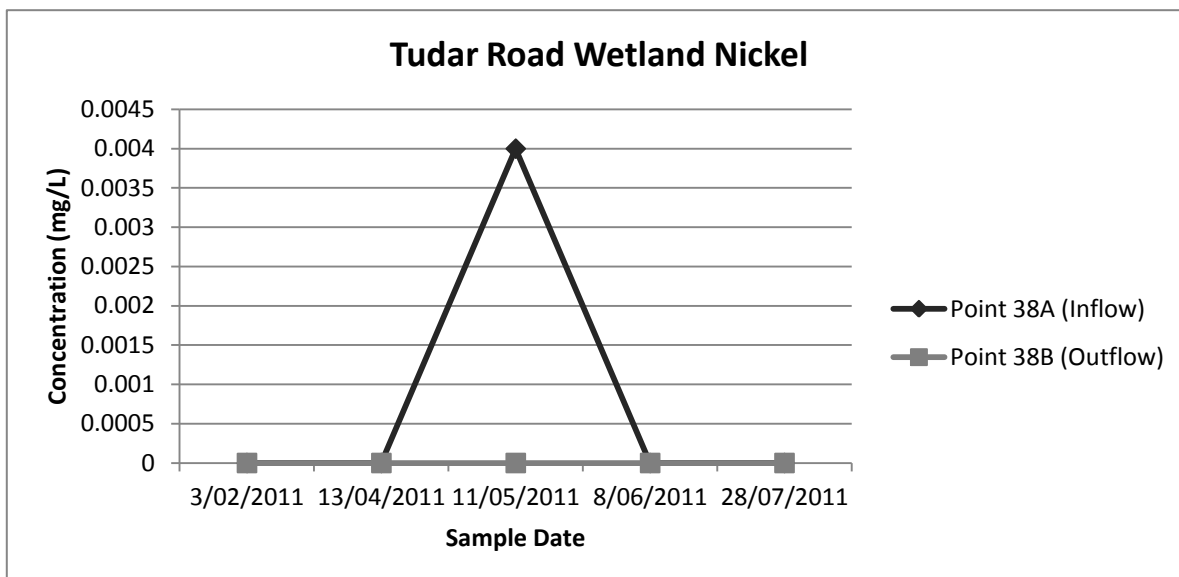


Figure 3.28 Tudor Road Wetland Nickel (LOR = 0.001).

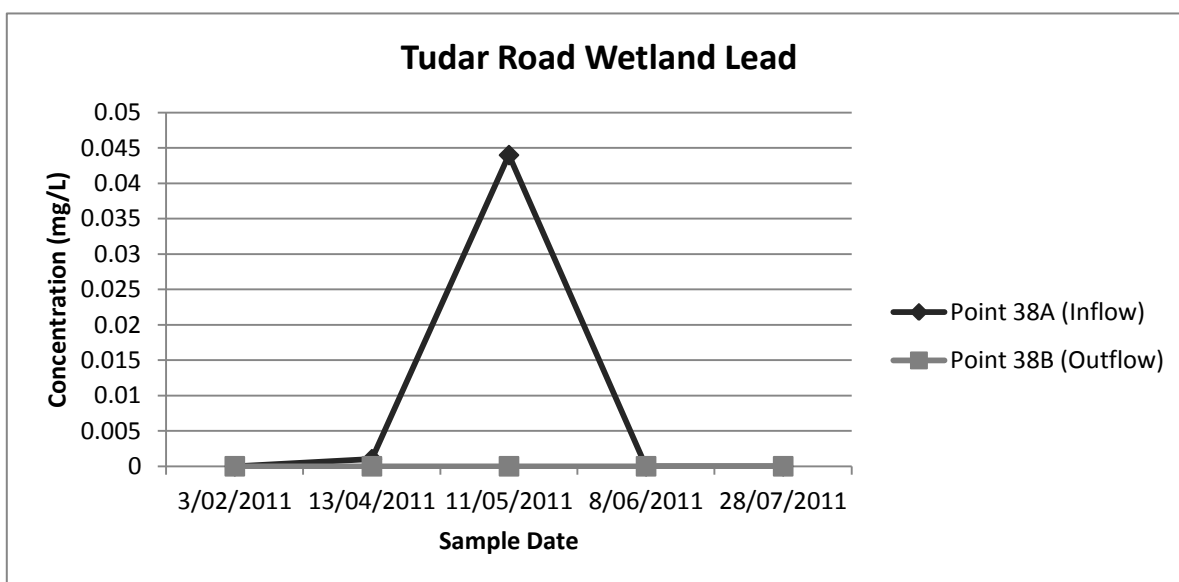


Figure 3.29 Tudor Road Wetland Lead (LOR = 0.001).

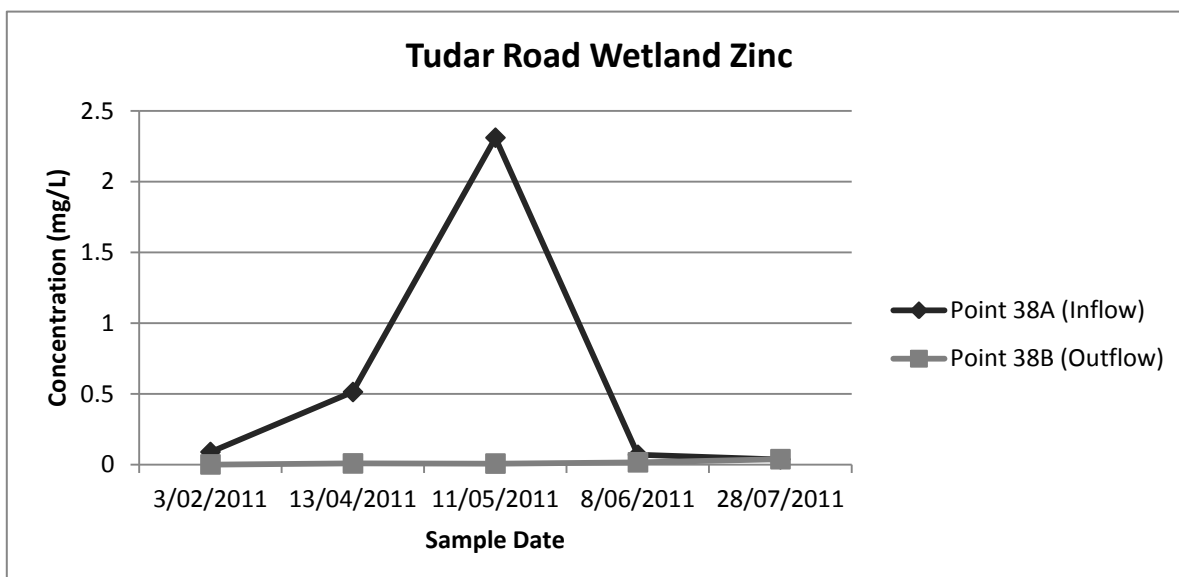


Figure 3.30 Tudor Road Wetland Zinc (LOR = 0.005).

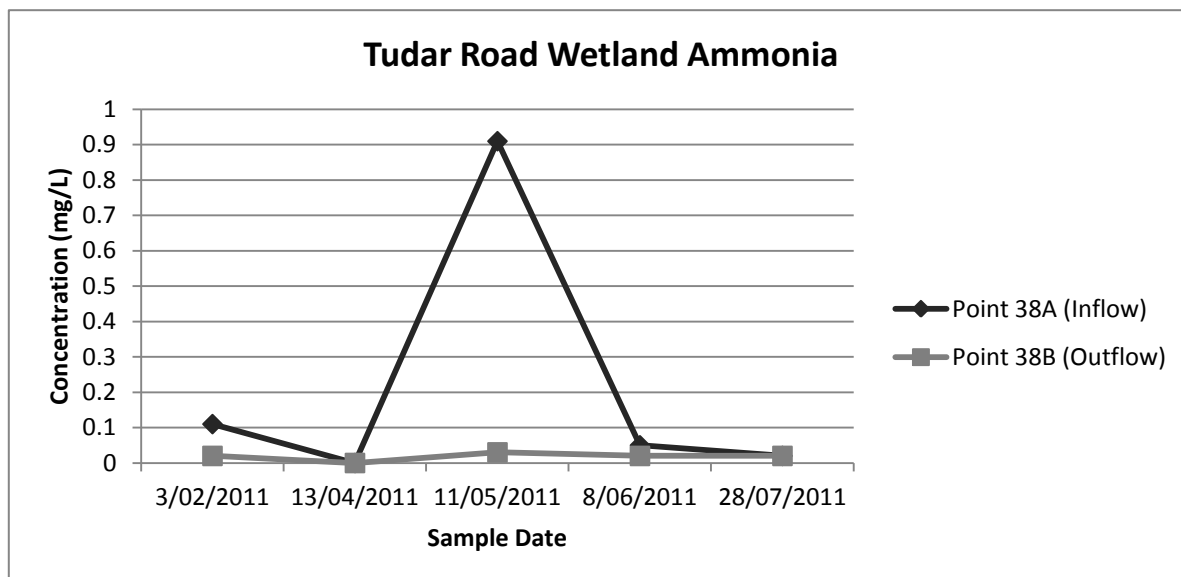


Figure 3.31 Tudor Road Wetland Ammonia (LOR = 0.01).

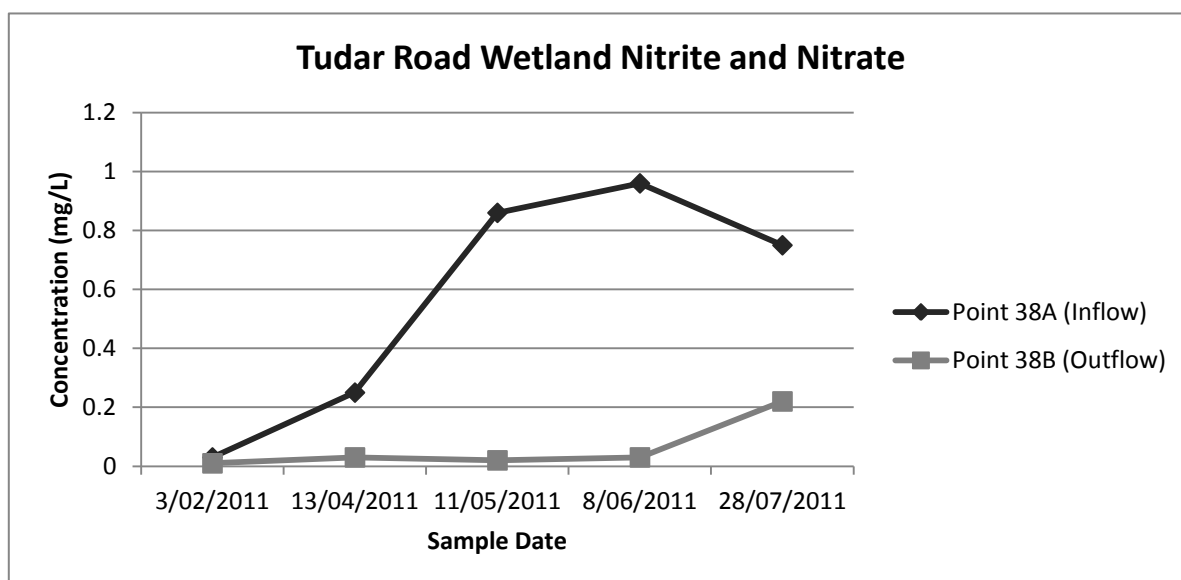


Figure 3.32 Tudor Road Wetland Nitrite and Nitrate (LOR = 0.01).

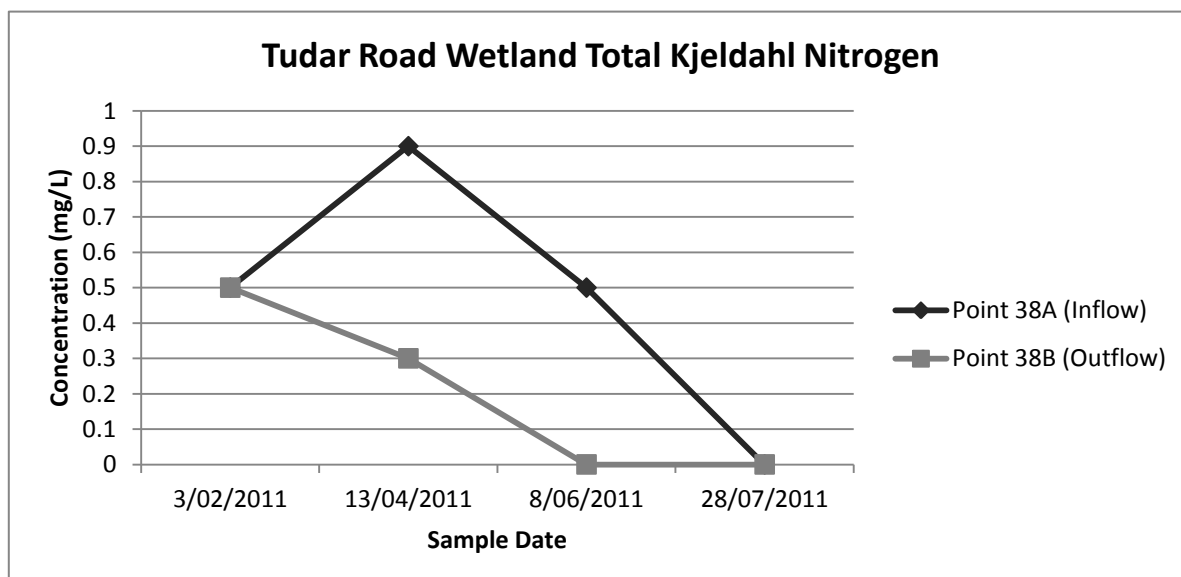


Figure 3.33 Tudor Road Wetland Total Kjeldahl Nitrogen (LOR = 0.1).



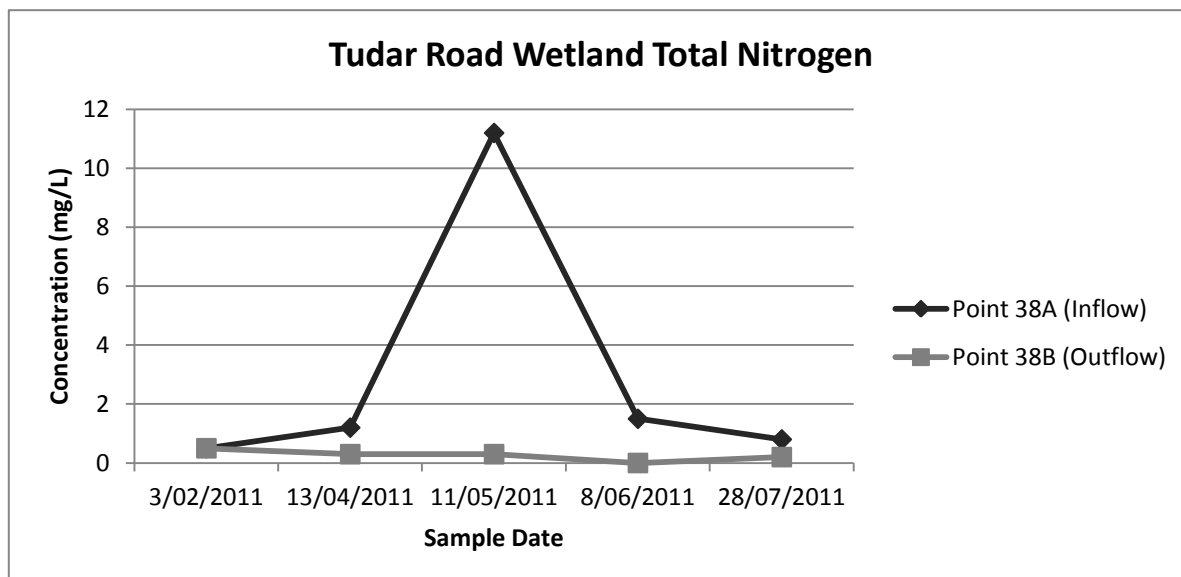


Figure 3.34 Tudor Road Wetland Total Nitrogen (LOR = 0.1).

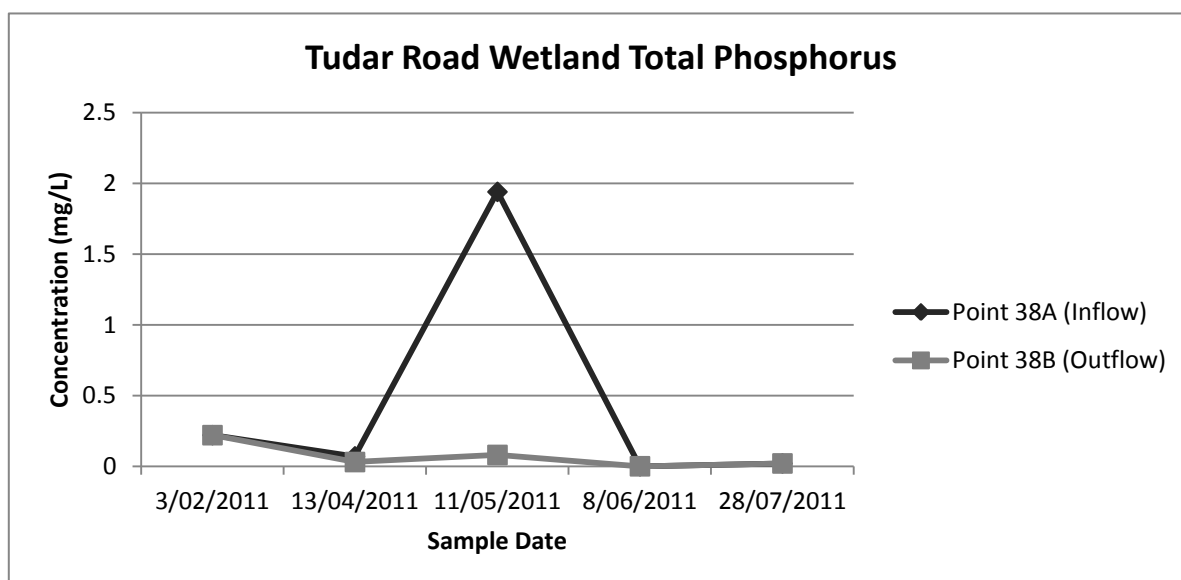


Figure 3.35 Tudor Road Wetland Total Phosphorus. (LOR = 0.01)

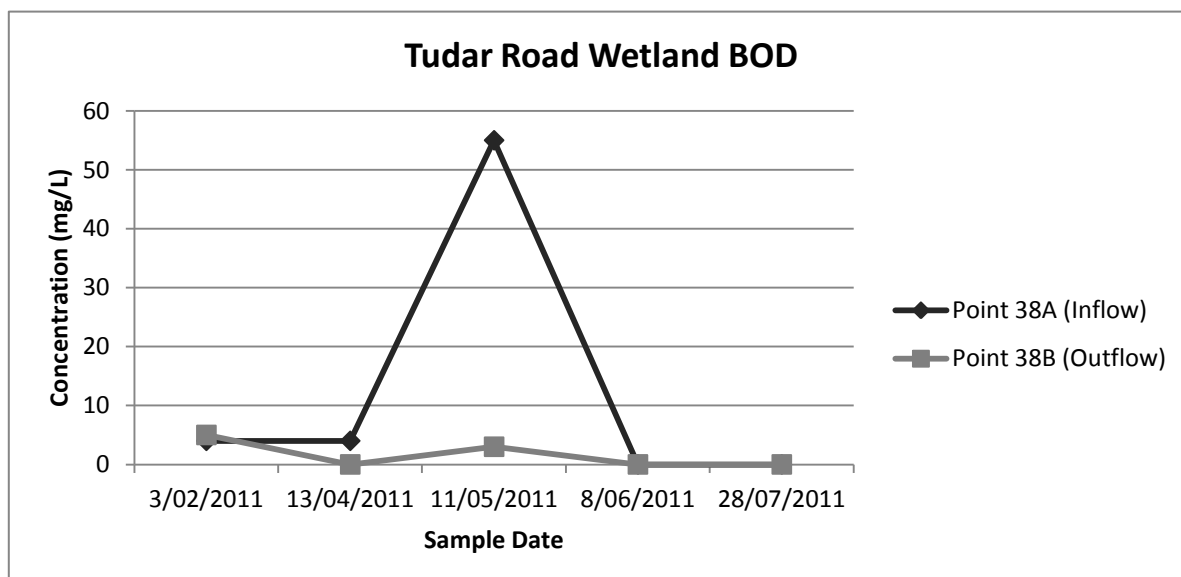


Figure 3.36 Tudor Road Wetland BOD (LOR = 2).

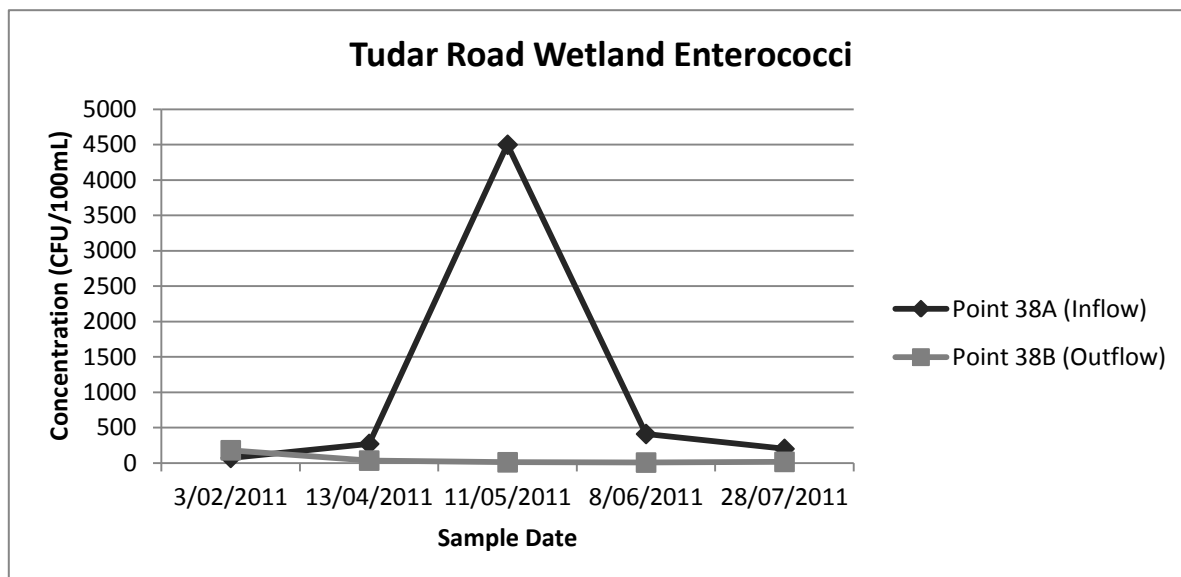


Figure 3.37 Tudar Road Wetland *Enterococci* (LOR = 1).

### 3.1.3 Still Creek Detention Basin

Reviewing the field parameters for Still Creek Detention Basin (Table 3.3) it can be seen that there is little change in the temperature (Fig. 3.41) between the inflow and the outflow and a steady decrease in water temperature was recorded over the course of the sampling period. The curves for pH (Fig. 3.38) and dissolved oxygen (Fig. 3.40) indicate that an association between the inflow and the outflow does exist, such that the inflow demonstrates higher readings than the outflow. This was true for pH with the exception of 11/5/2011, where both measurements returned the same result. Studying the electrical conductivity (Fig. 3.39) and suspended solids (Fig. 3.42) graphs, it can be seen that a rough association is evident between the inflow and outflow, though nothing clear enough to base any assumptions on. Assessing the metals it can be seen that arsenic, nickel and lead were all below the LOR for both the inflow and outflow. Chromium (Fig. 3.44) was also below or equal to the LOR for all sampling dates with the exception of 28/7/2011, where a sharp increase in chromium concentration was recorded at the inflow. The outflow however on this occasion remained below the LOR. Cadmium (Fig. 3.43) experienced a sharp increase in inflow concentration on 3/2/2011, which unlike the chromium example was matched by an increase in the outflow concentration. This increase in outflow concentration remained below the inflow level and all following measurements were equal to or below the LOR. Copper (Fig. 3.45) and zinc (Fig. 3.46) both expressed a correlation between the inflow and outflow with the inflow values being greater than or equal to the outflow. Elevated levels of copper and zinc were detected on 13/4/2011 and 28/7/2011 with all other values being equal to or less than the LOR. The



graphs for ammonia (Fig. 3.47), TKN (Fig. 3.49) and total phosphorus (Fig. 3.51) all show little association between the inflow and the outflow, which is particularly evident with the TKN curve. On the other hand, nitrite and nitrate (Fig. 3.48) and total nitrogen (Fig. 3.50) both demonstrate a clear correlation, with these parameters showing higher readings at the inflow and the concentrations increasing over the course of the sampling period. Conversely, BOD (Fig. 3.52) and *Enterococci* (Fig. 3.53) convey the existence of increased concentrations at the outflow with corresponding reductions at the inflow.

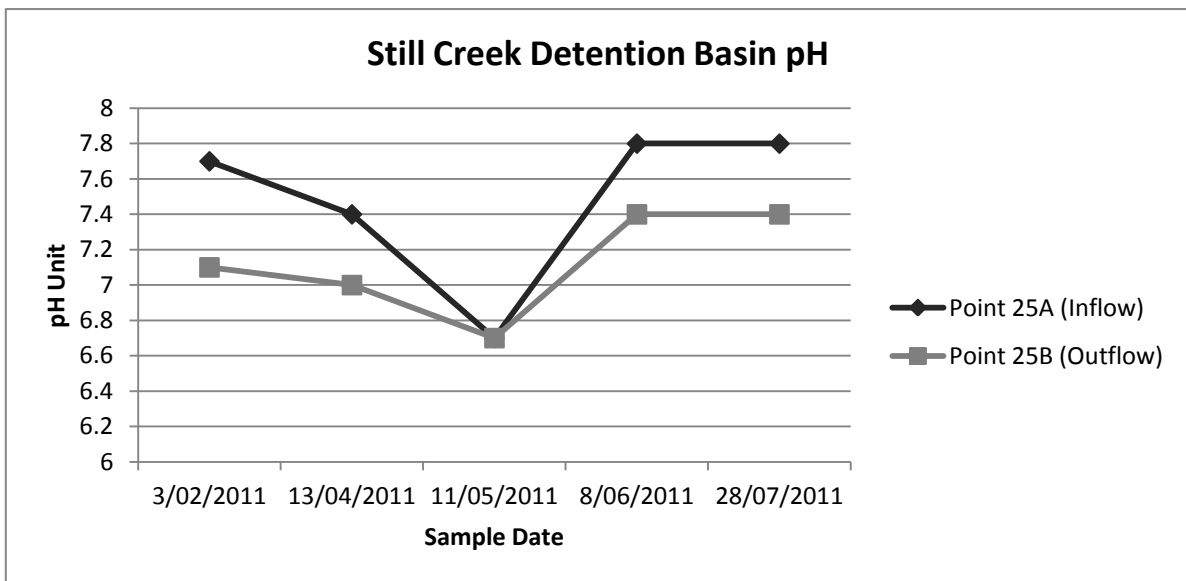


Figure 3.38 Still Creek Detention Basin pH (LOR = 0.1).

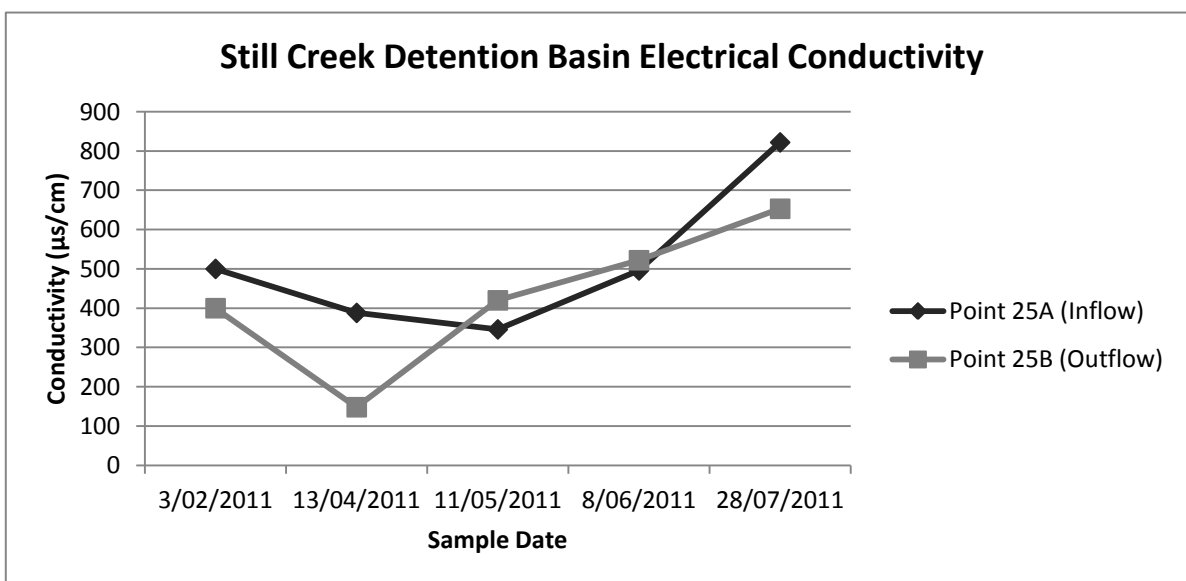


Figure 3.39 Still Creek Detention Basin Electrical Conductivity (LOR = 1).

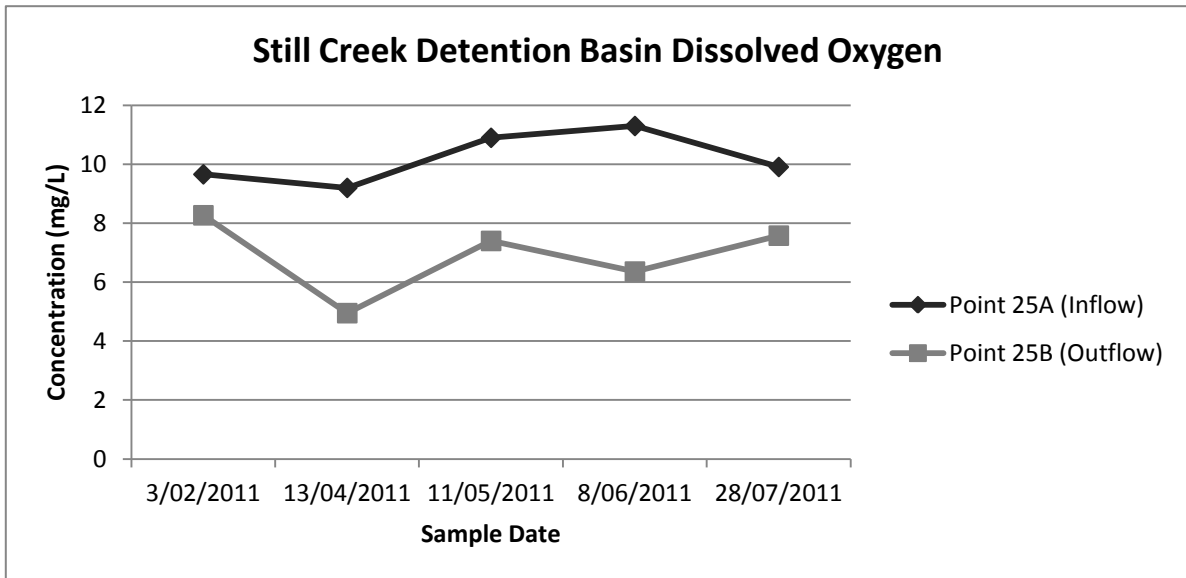


Figure 3.40 Still Creek Detention Basin Dissolved Oxygen (LOR = 0.01).

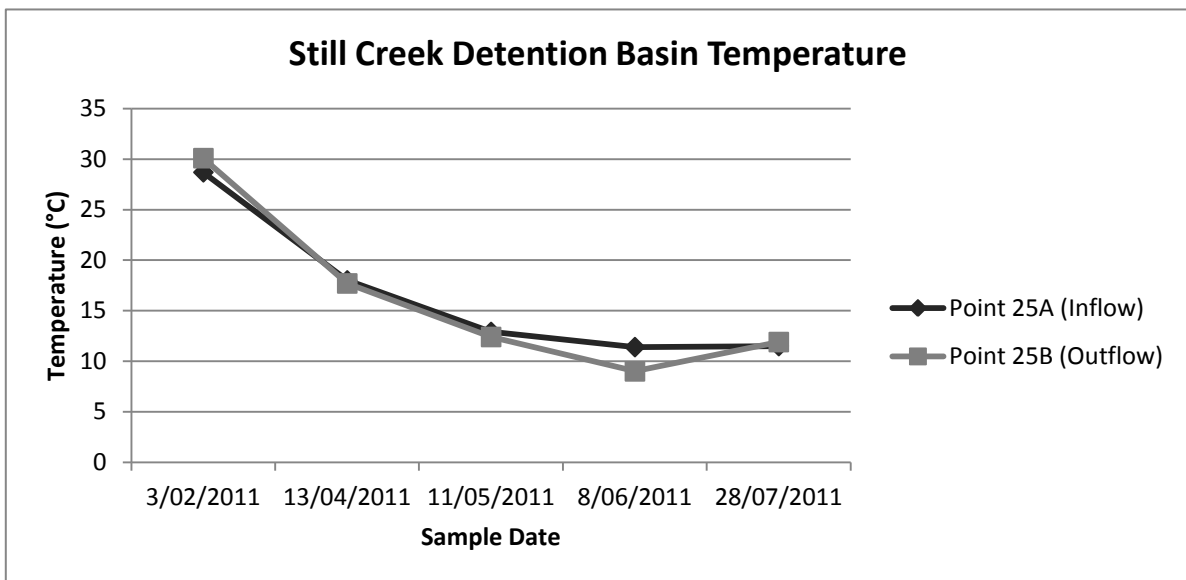


Figure 3.41 Still Creek Detention Basin Temperature (LOR = 0.1).

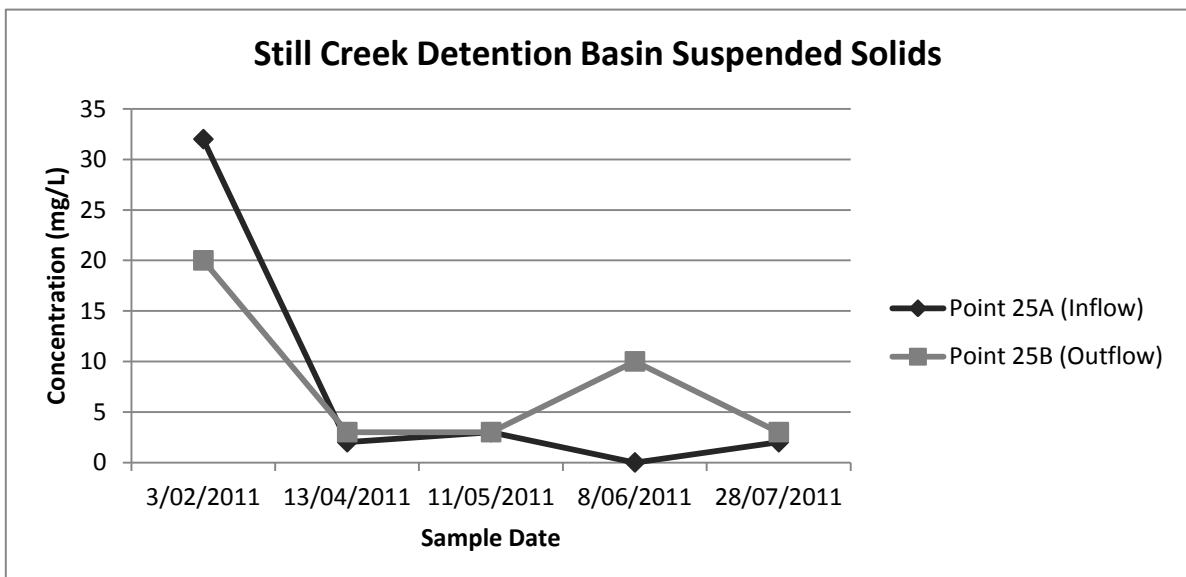


Figure 3.42 Still Creek Detention Basin Suspended Solids (LOR = 1).



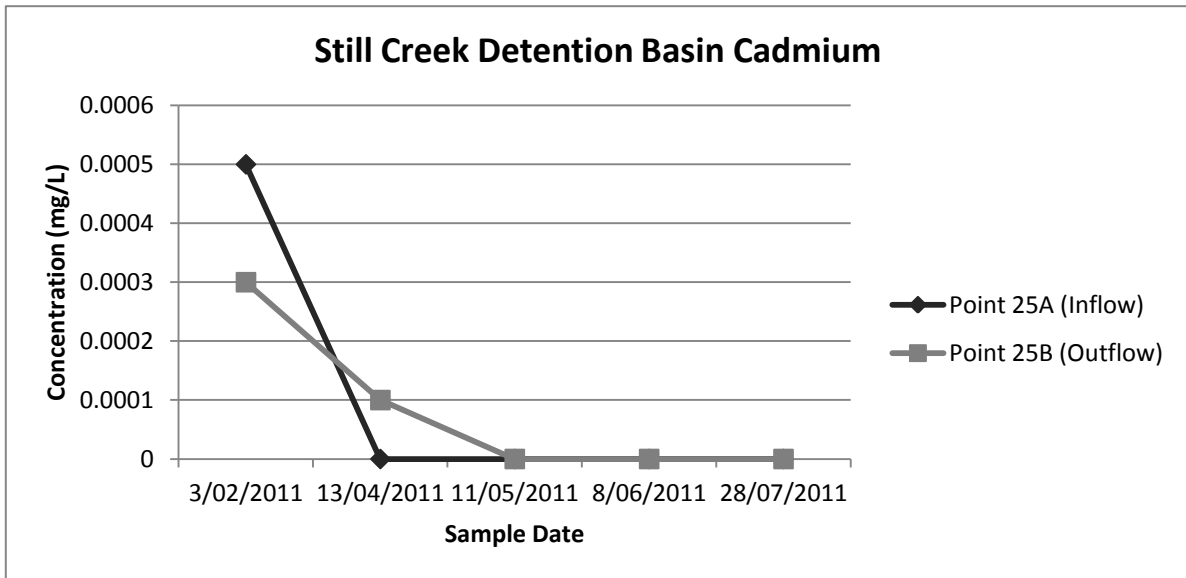


Figure 3.43 Still Creek Detention Basin Cadmium (LOR = 0.0001).

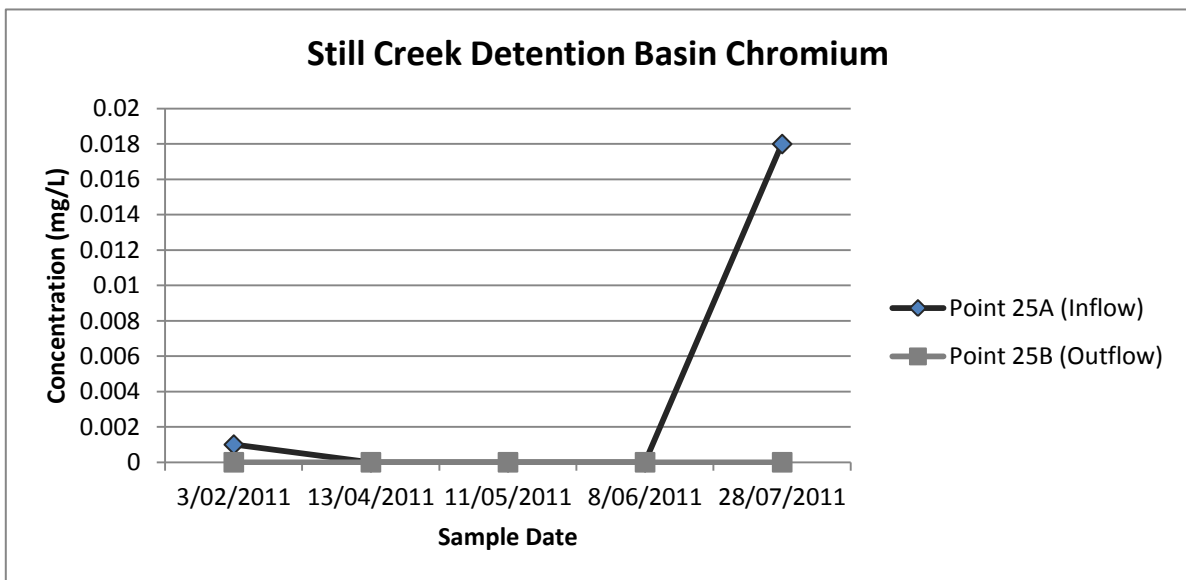


Figure 3.44 Still Creek Detention Basin Chromium (LOR = 0.001).

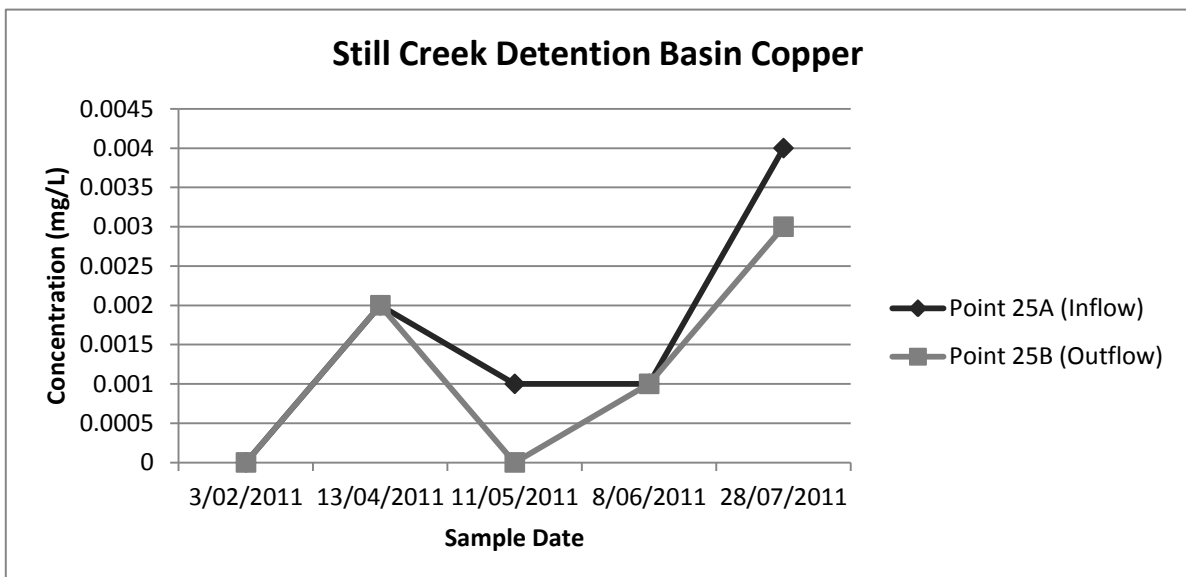


Figure 3.45 Still Creek Detention Basin Copper (LOR = 0.001).

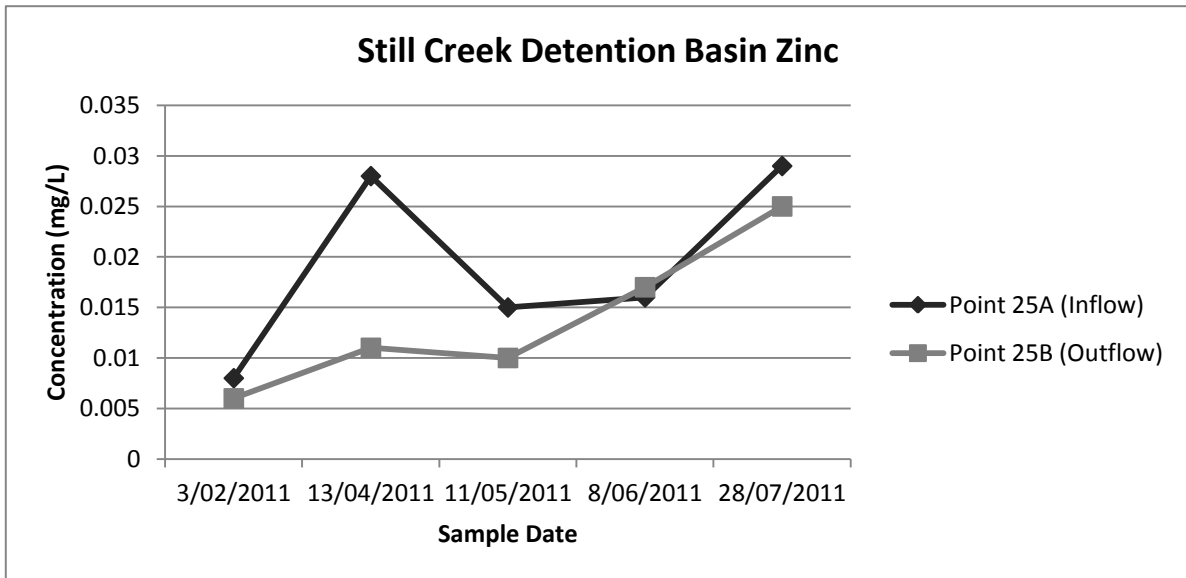


Figure 3.46 Still Creek Detention Basin Zinc (LOR = 0.005).

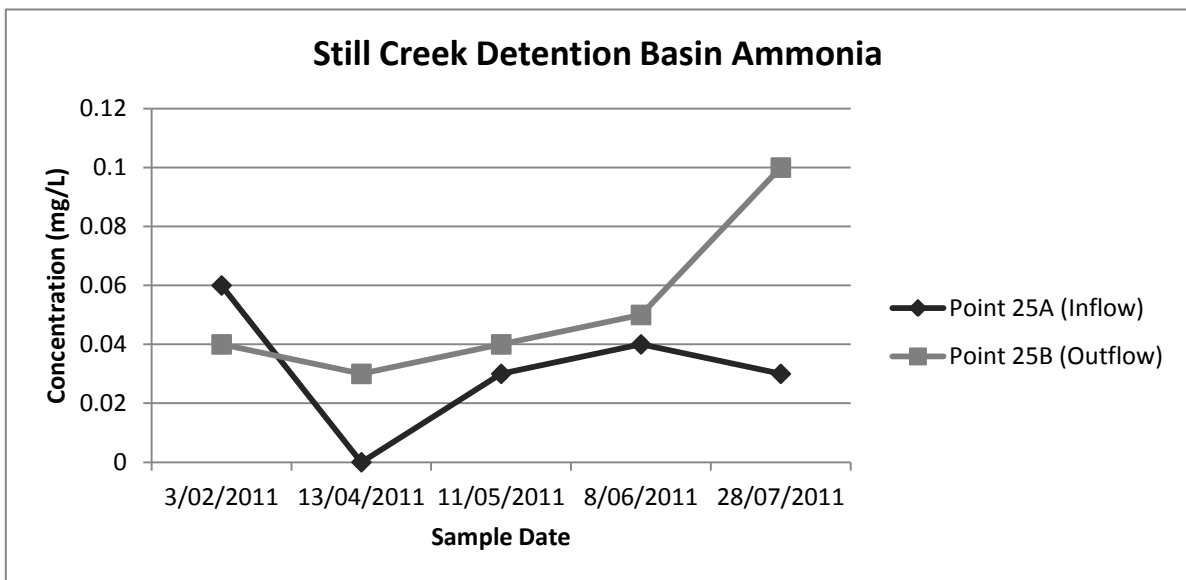


Figure 3.47 Still Creek Detention Basin Ammonia (LOR = 0.01).

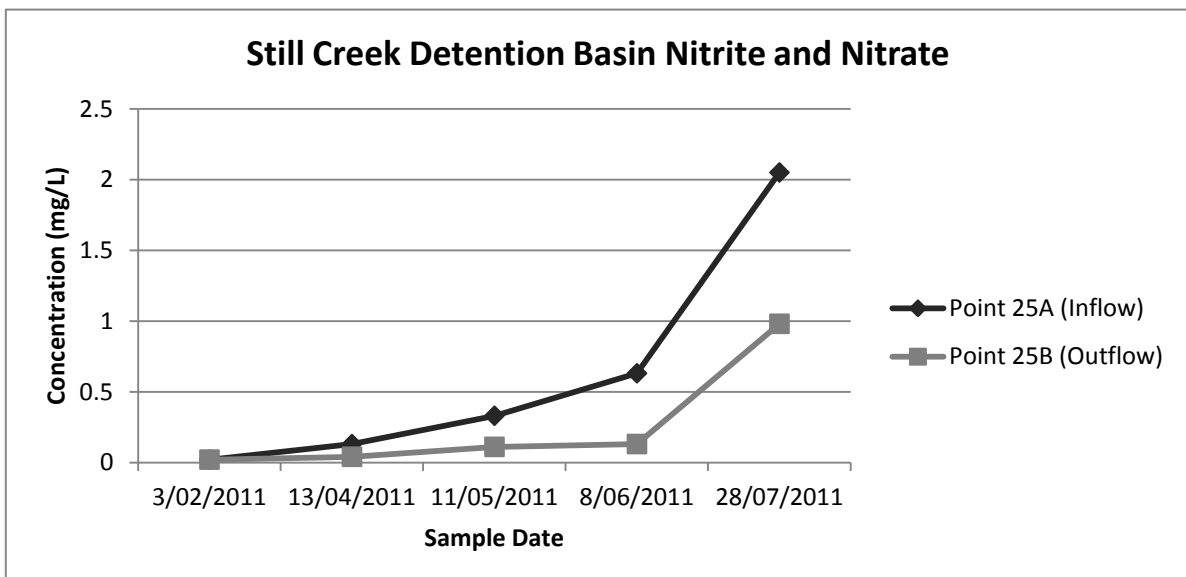


Figure 3.48 Still Creek Detention Basin Nitrite and Nitrate (LOR = 0.01).



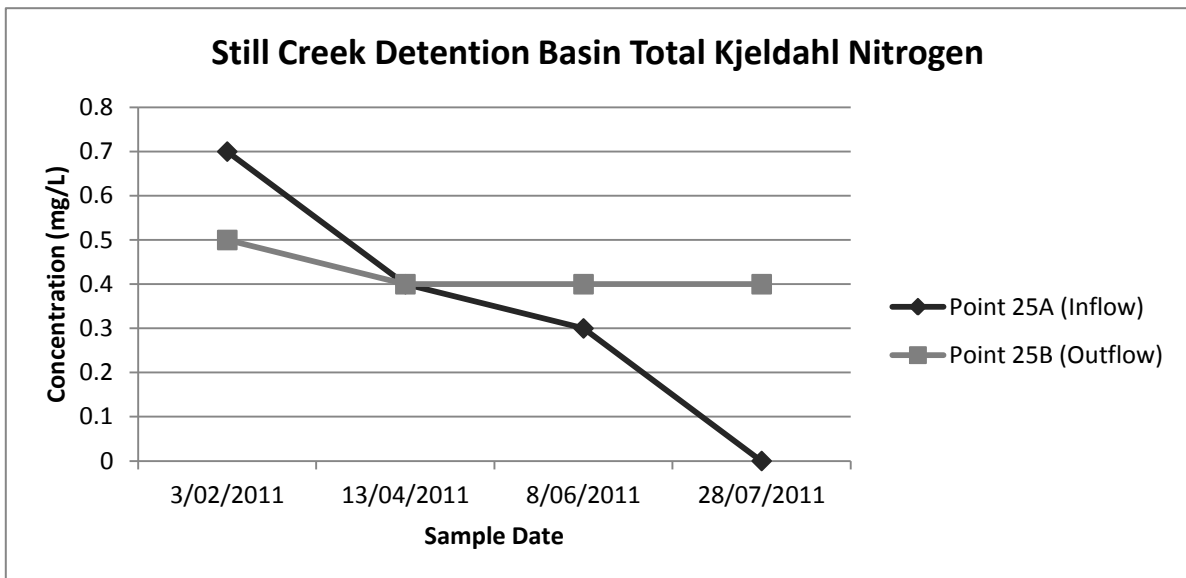


Figure 3.49 Still Creek Detention Basin Total Kjeldahl Nitrogen (LOR = 0.1).

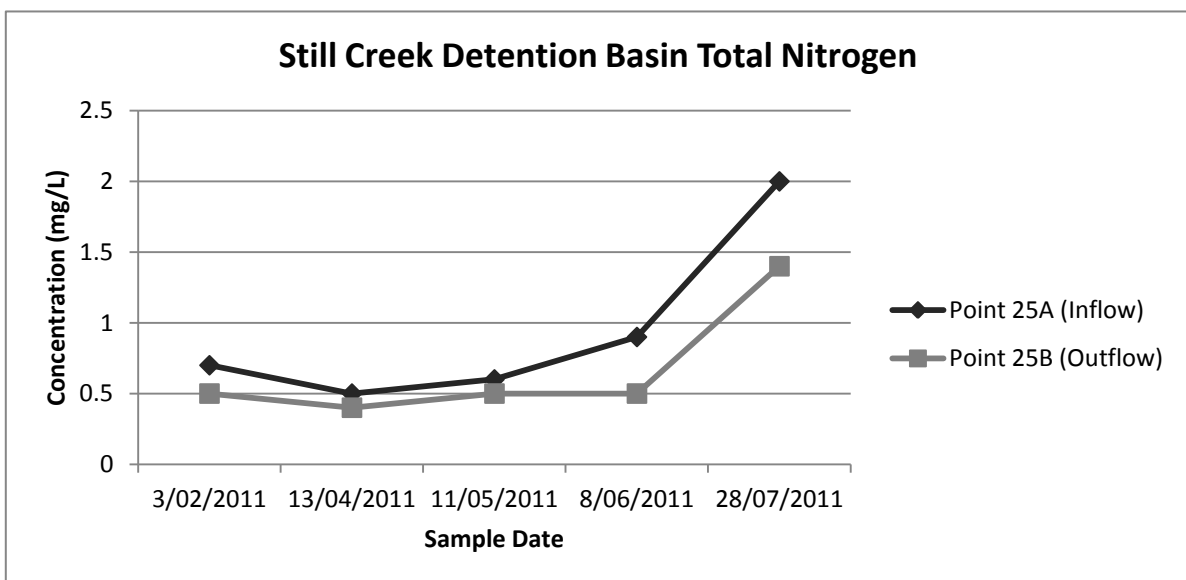


Figure 3.50 Still Creek Detention Basin Total Nitrogen (LOR = 0.1).

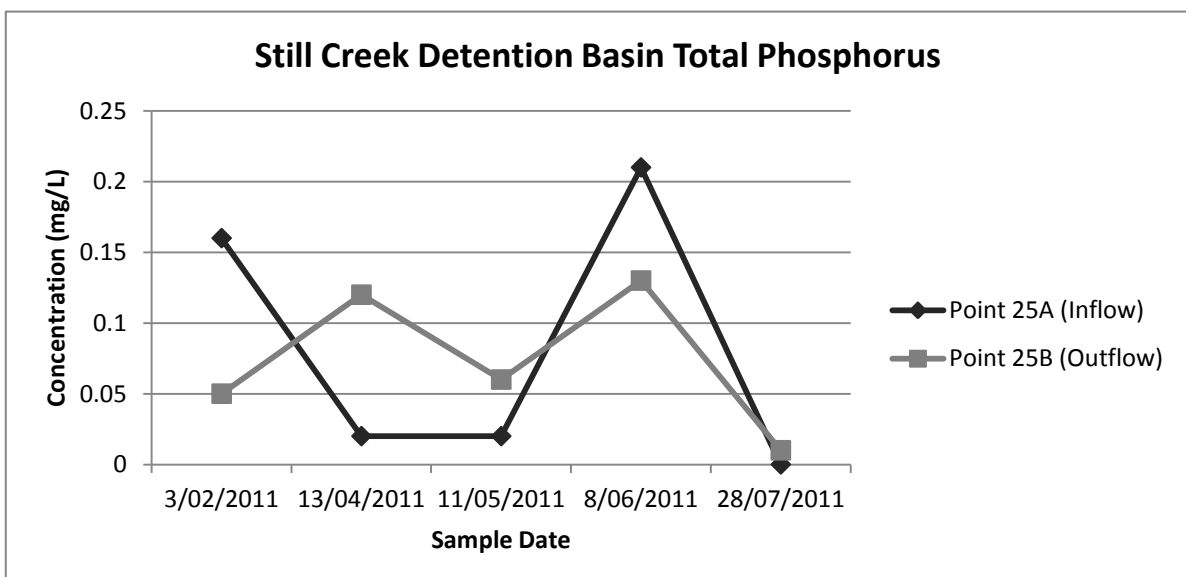


Figure 3.51 Still Creek Detention Basin Total Phosphorus (LOR = 0.01).

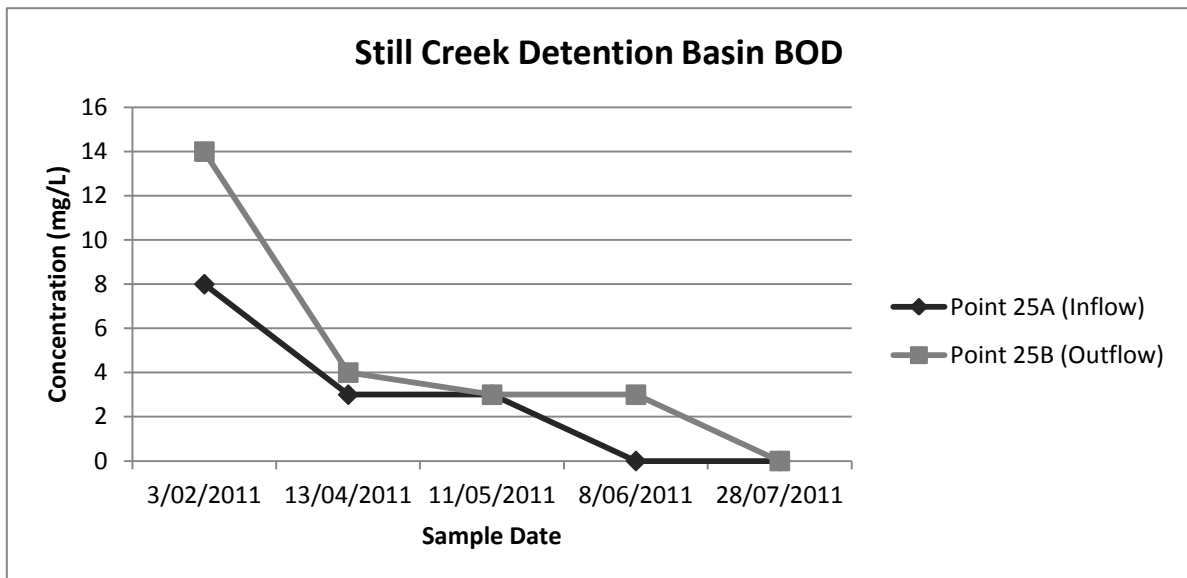


Figure 3.52 Still Creek Detention Basin BOD (LOR = 2).

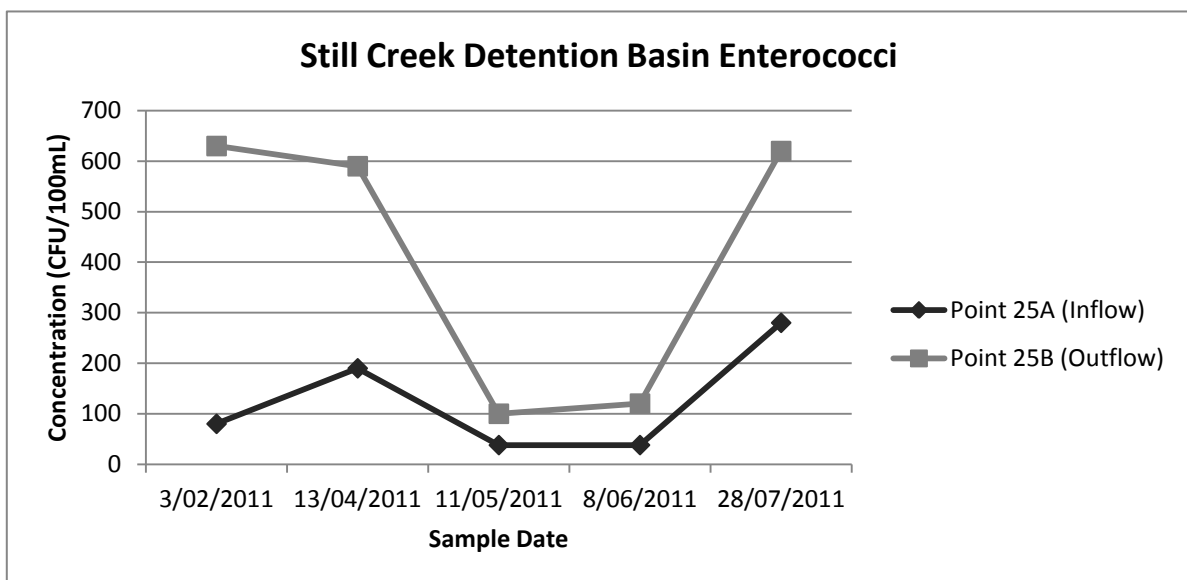


Figure 3.53 Still Creek Detention Basin *Enterococci* (LOR = 1).

### 3.1.4 Burnum Burnum Detention Basin

Burnum Burnum Detention Basin (Table 3.4) does not appear to display any relationship between the inflow and outflow measurements for pH (Fig. 3.54) or electrical conductivity (Fig. 3.55). Dissolved oxygen (Fig. 3.56) and temperature (Fig. 3.57) are conversely related such that as temperature falls, dissolved oxygen rises. The graph for suspended solids (Fig. 3.58) shows that a reasonable degree of variation exists between each sampling event and that little correlation can be observed between the inflow and the outflow. Examining the metals it can be seen that arsenic (Fig. 3.59) concentrations are low with the exception of 3/2/2011,



when a raised value was observed at the outflow. The high suspended solids level on 13/4/2011 corresponds well with increases in cadmium (Fig. 3.60), chromium (Fig. 3.61), copper (Fig. 3.62), nickel (Fig. 3.63), lead (Fig. 3.64) and zinc (Fig. 3.65). Similar to Tudar Road Wetland, the raised suspended solids values also correlate well with ammonia (Fig. 3.66), TKN (Fig. 3.68), total nitrogen (Fig. 3.69), BOD (Fig. 3.71) and *Enterococci* (Fig. 3.72). Due to variation between sampling events, not all the curves for these parameters were as characteristically pyramid shaped as those seen at Tudar Road Wetland, though some were, including cadmium, chromium, lead, zinc and *Enterococci*. Interestingly, the same pattern observed at Tudar Road Wetland for nitrite and nitrate (Fig. 3.67) was observed here. Total phosphorus (Fig. 3.70) does not show any association with the elevated suspended solids on 13/4/2011, although perhaps a weak correlation between the outflow and the inflow can be described.

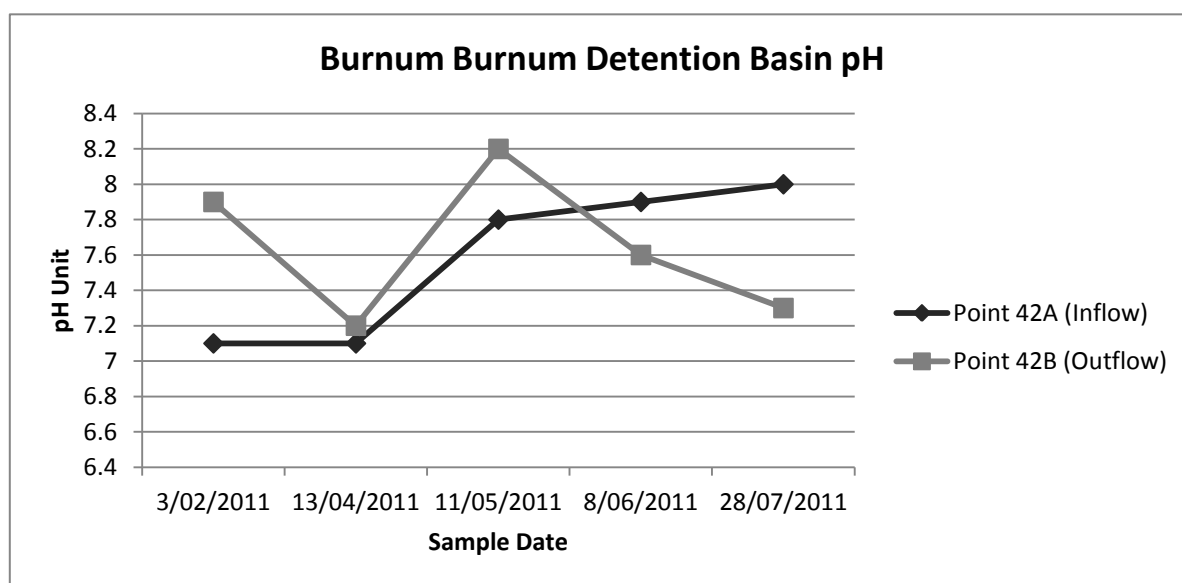


Figure 3.54 Burnum Burnum Detention Basin pH (LOR = 0.1).

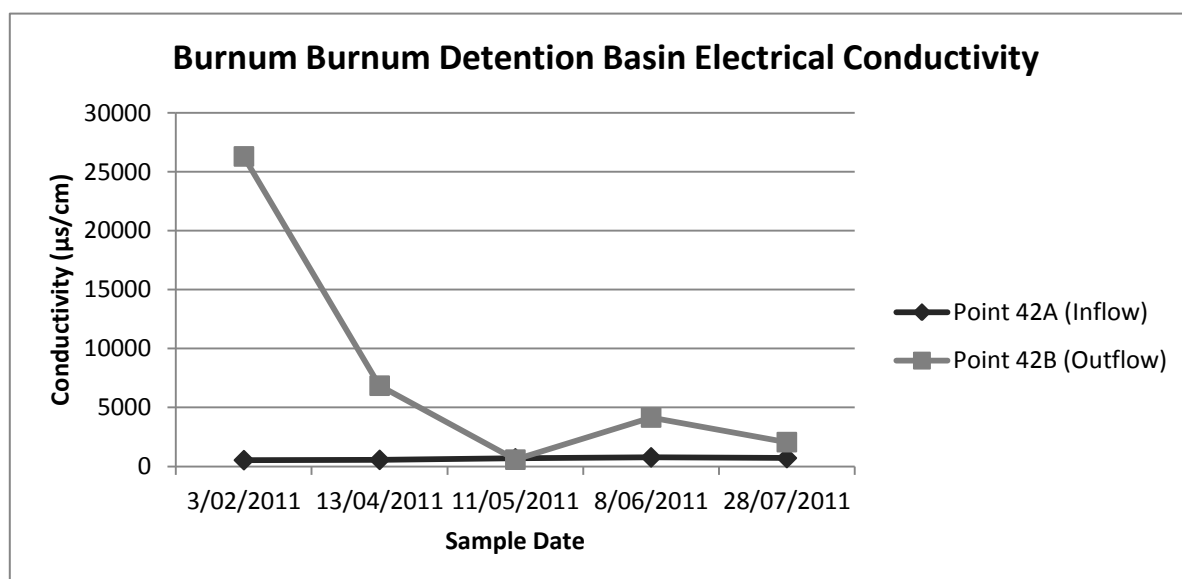


Figure 3.55 Burnum Burnum Detention Basin Electrical Conductivity (LOR = 1).

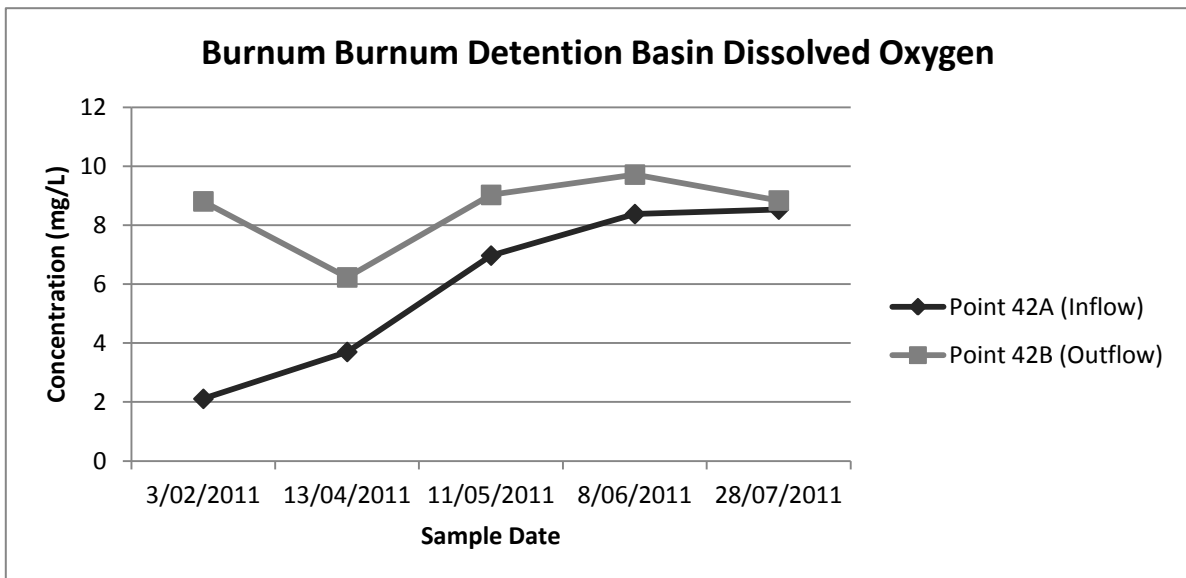


Figure 3.56 Burnum Burnum Detention Basin Dissolved Oxygen (LOR = 0.01).

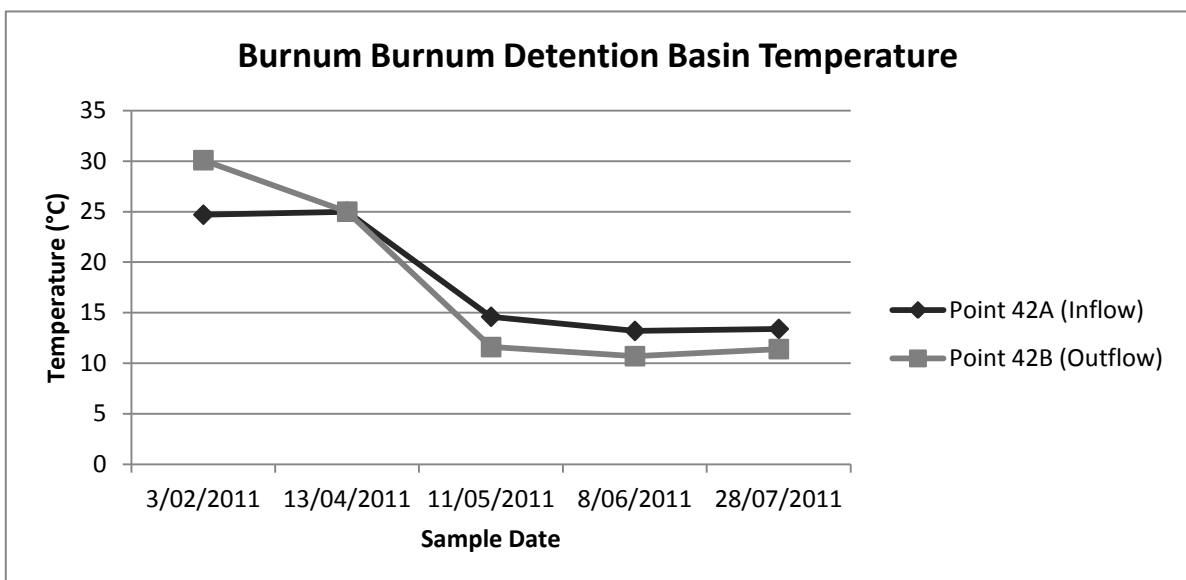


Figure 3.57 Burnum Burnum Detention Basin Temperature (LOR = 0.1).

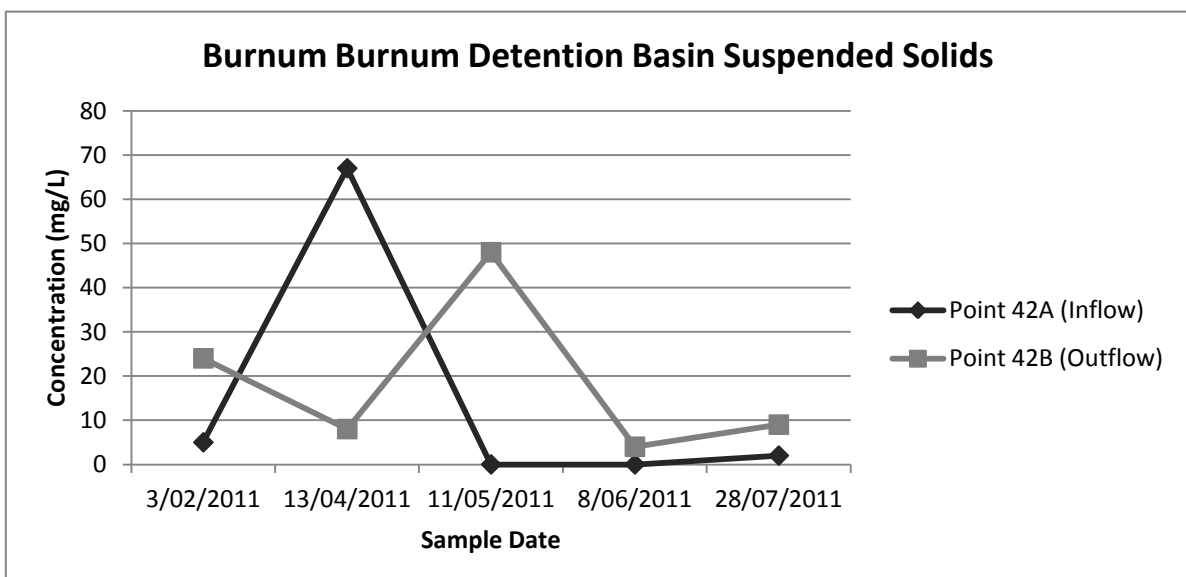


Figure 3.58 Burnum Burnum Detention Basin Suspended Solids (LOR = 1).



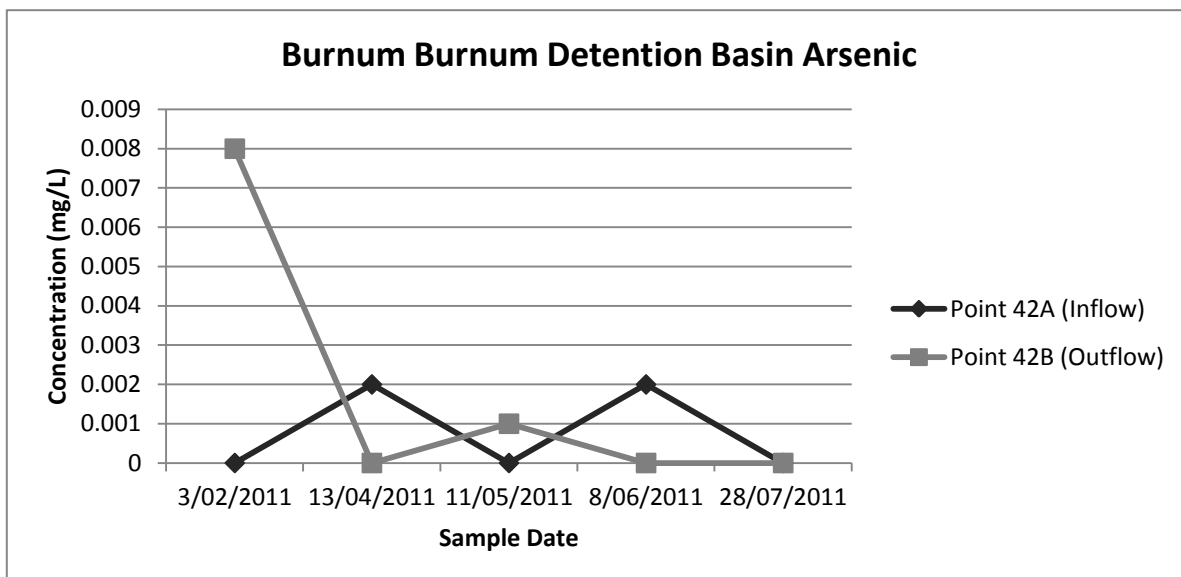


Figure 3.59 Burnum Burnum Detention Basin Arsenic (LOR = 0.001).

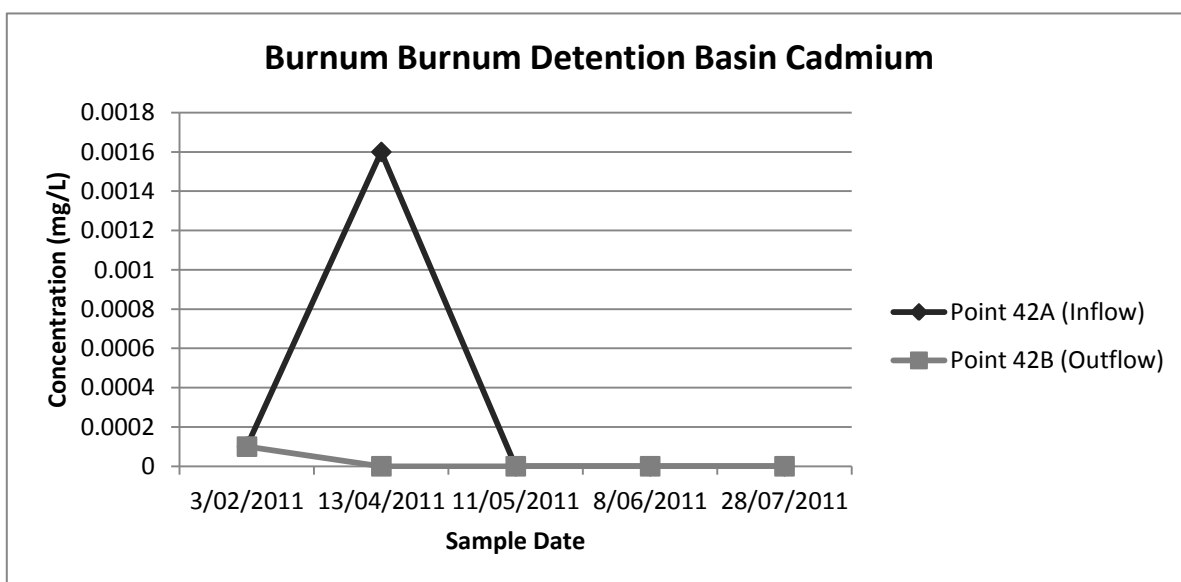


Figure 3.60 Burnum Burnum Detention Basin Cadmium (LOR = 0.0001).

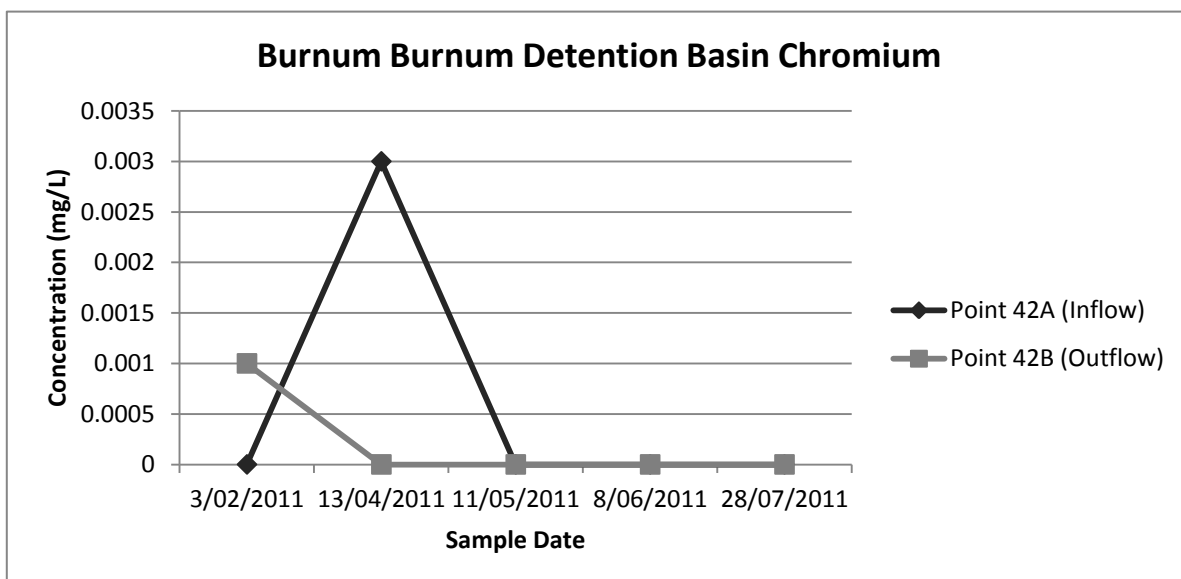


Figure 3.61 Burnum Burnum Detention Basin Chromium (LOR = 0.001).

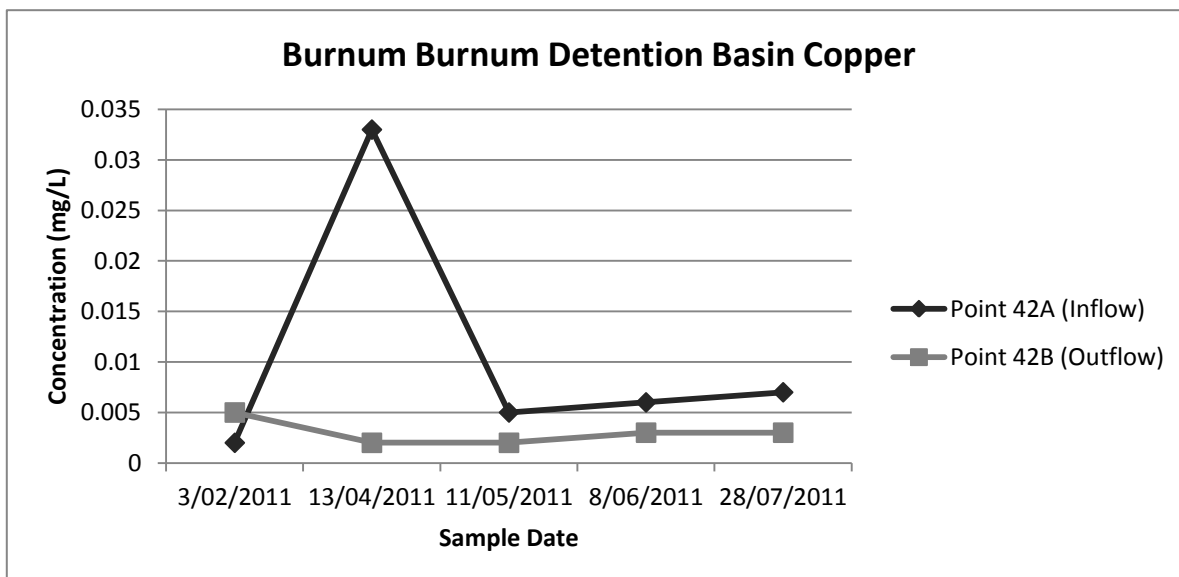


Figure 3.62 Burnum Burnum Detention Basin Copper (LOR = 0.001).

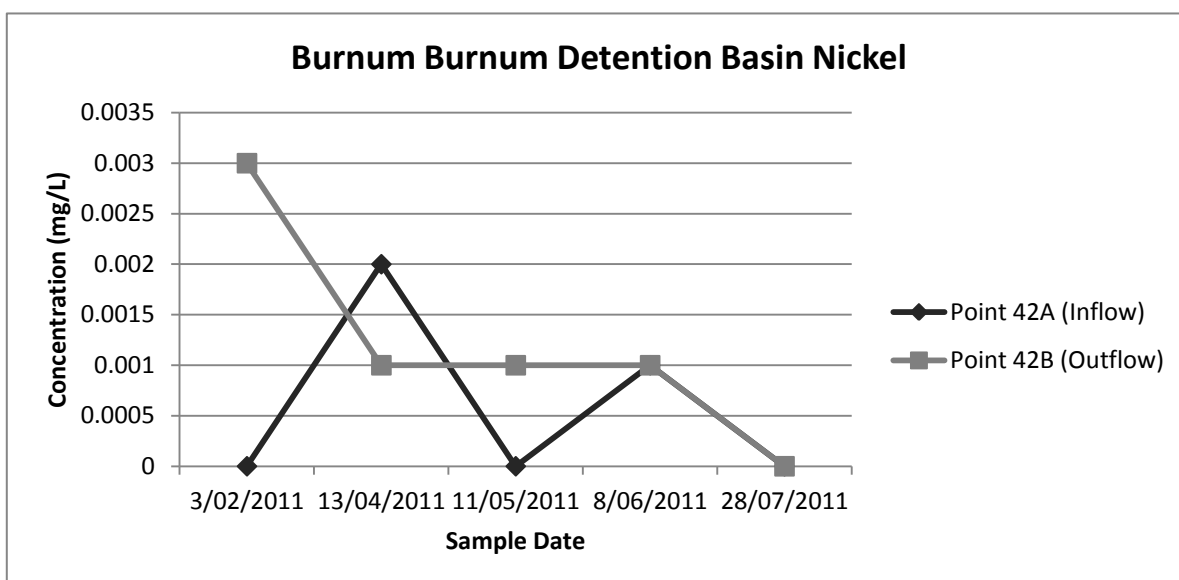


Figure 3.63 Burnum Burnum Detention Basin Nickel (LOR = 0.001).

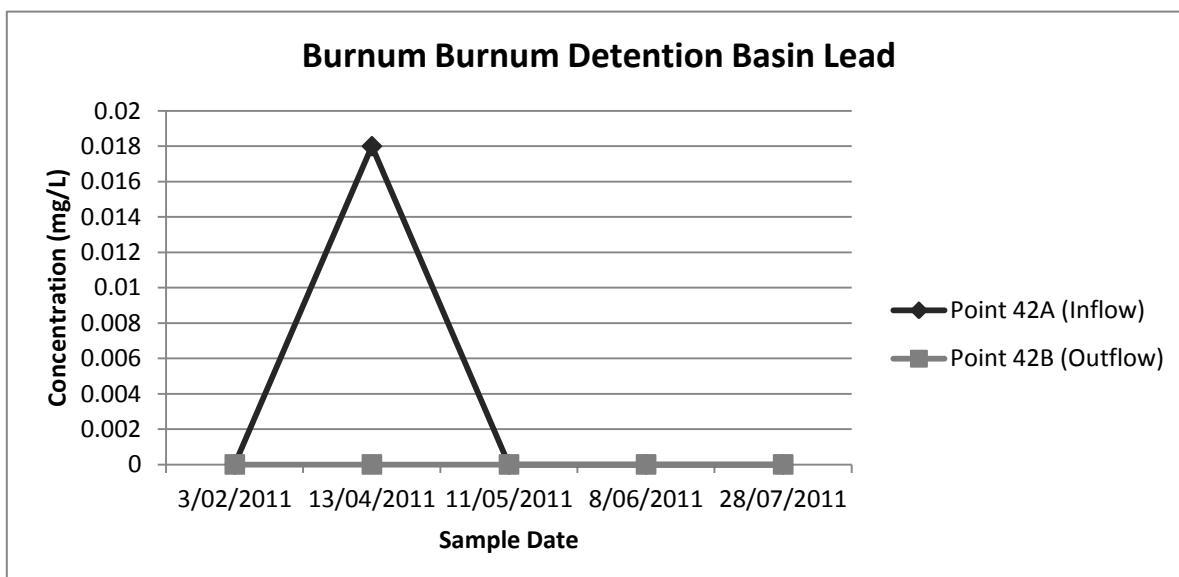


Figure 3.64 Burnum Burnum Detention Basin Lead (LOR = 0.001).



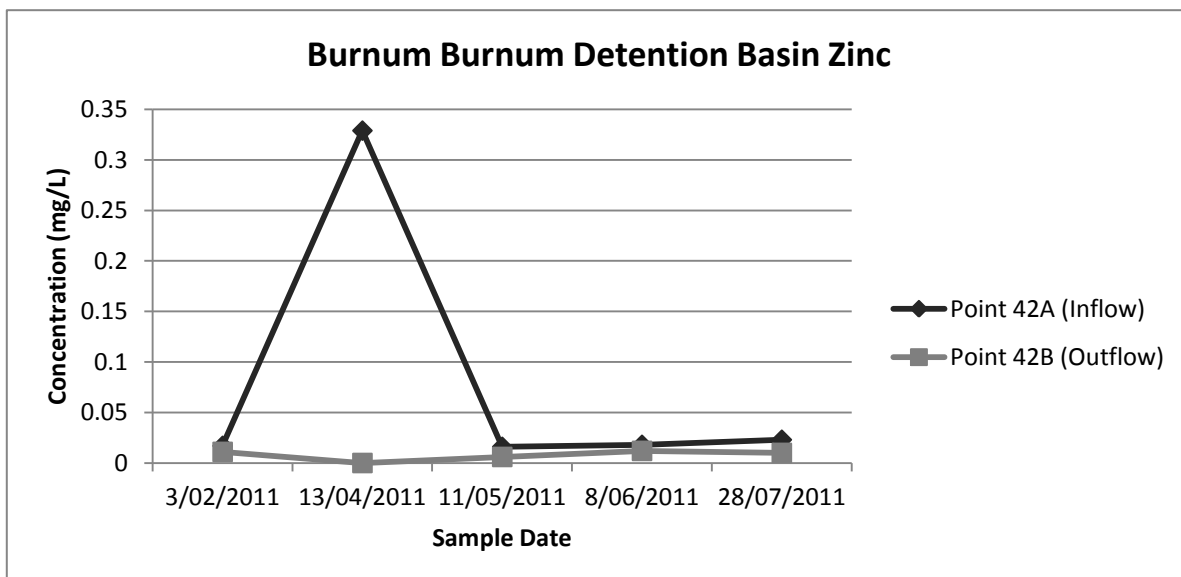


Figure 3.65 Burnum Burnum Detention Basin Zinc (LOR = 0.005).

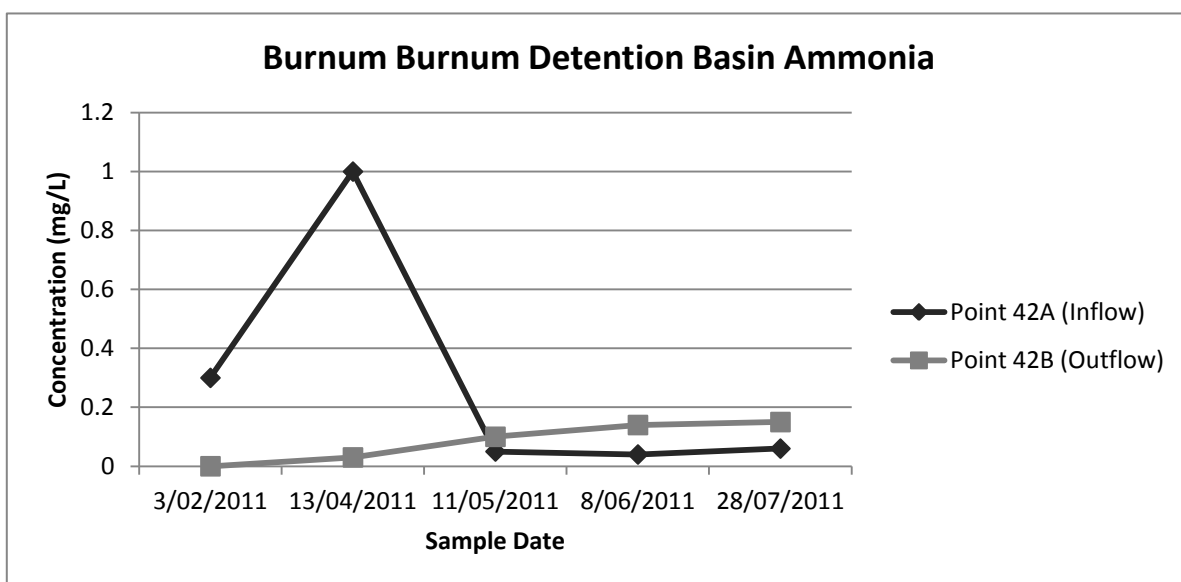


Figure 3.66 Burnum Burnum Detention Basin Ammonia (LOR = 0.01).

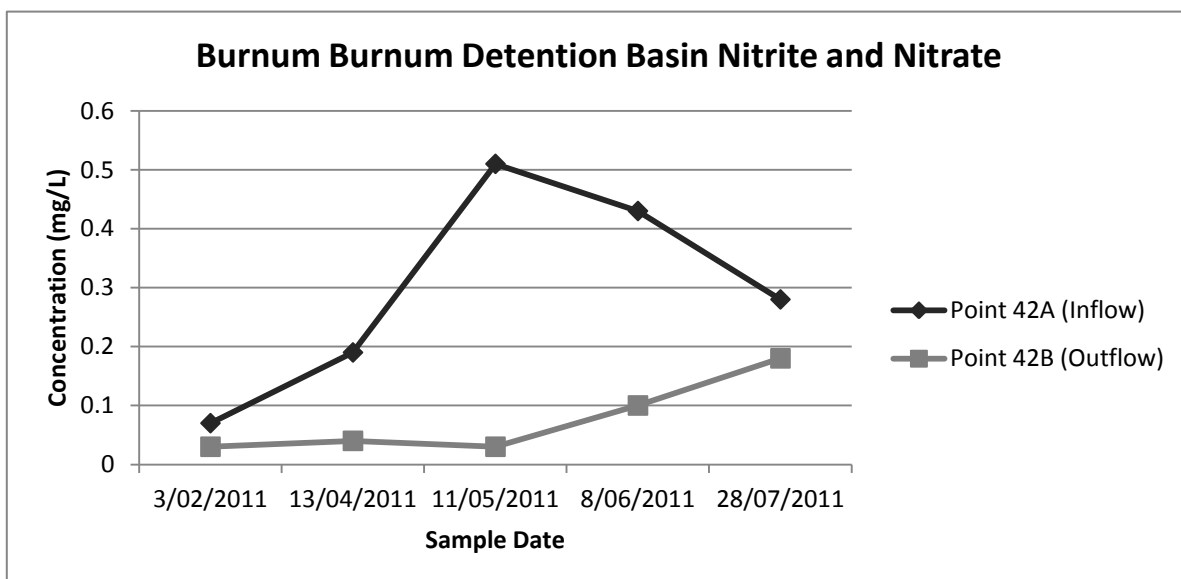


Figure 3.67 Burnum Burnum Detention Basin Nitrite and Nitrate (LOR = 0.01).

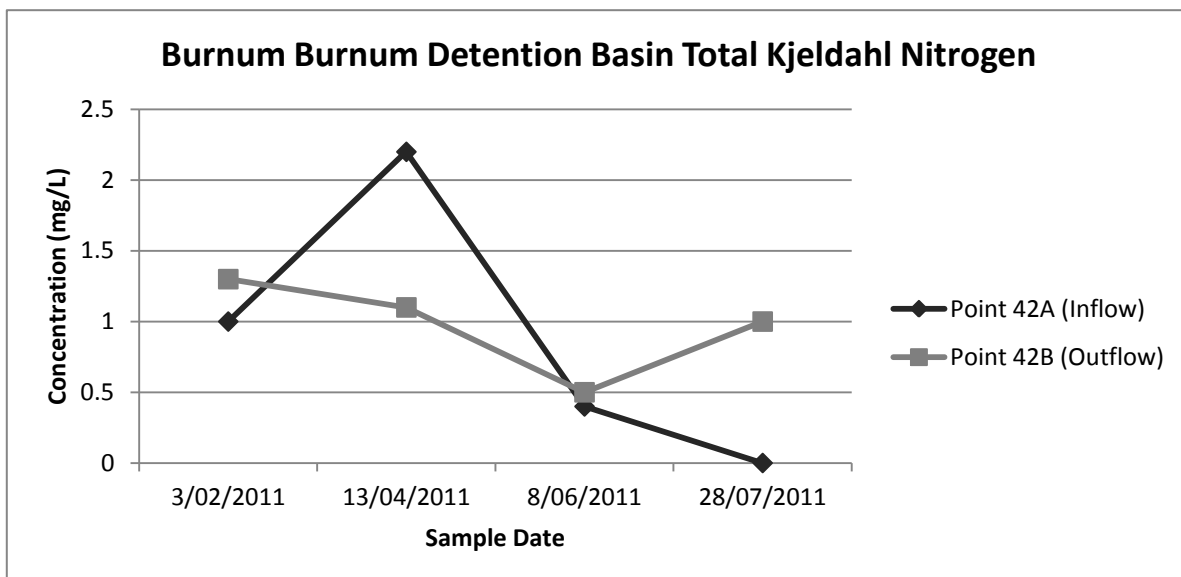


Figure 3.68 Burnum Burnum Detention Basin Total Kjeldahl Nitrogen (LOR = 0.1).

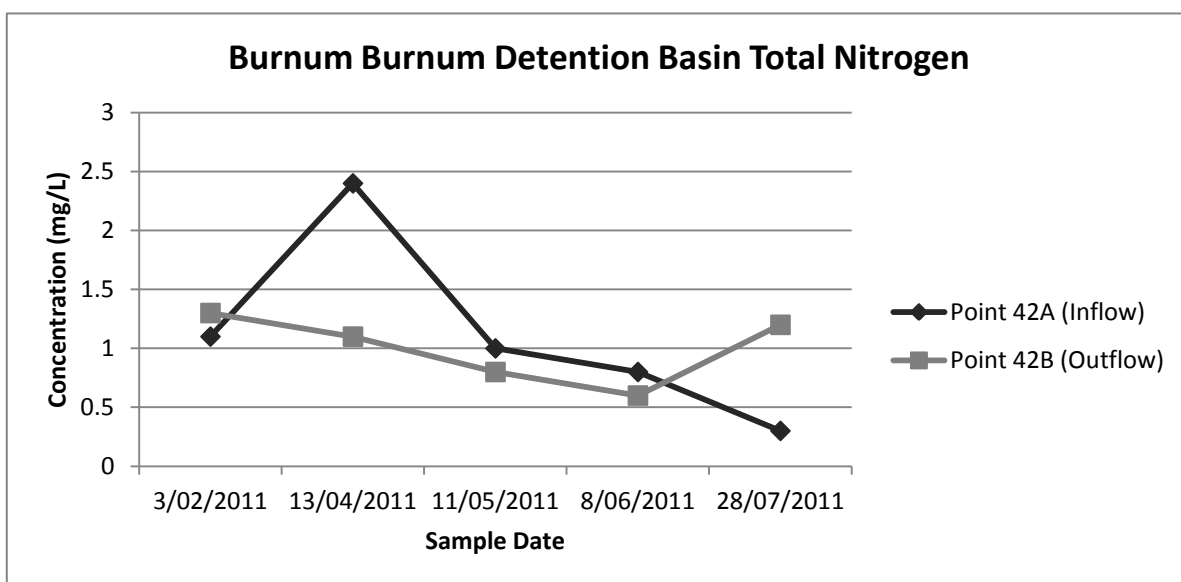


Figure 3.69 Burnum Burnum Detention Basin Total Nitrogen (LOR = 0.1).

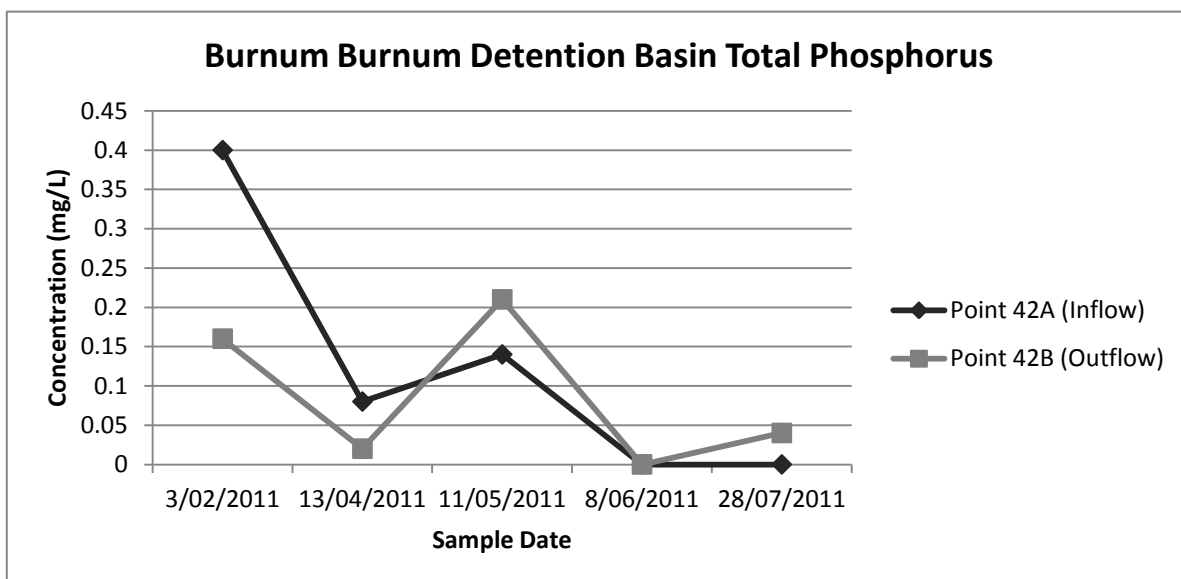


Figure 3.70 Burnum Burnum Detention Basin Total Phosphorus (LOR = 0.01).



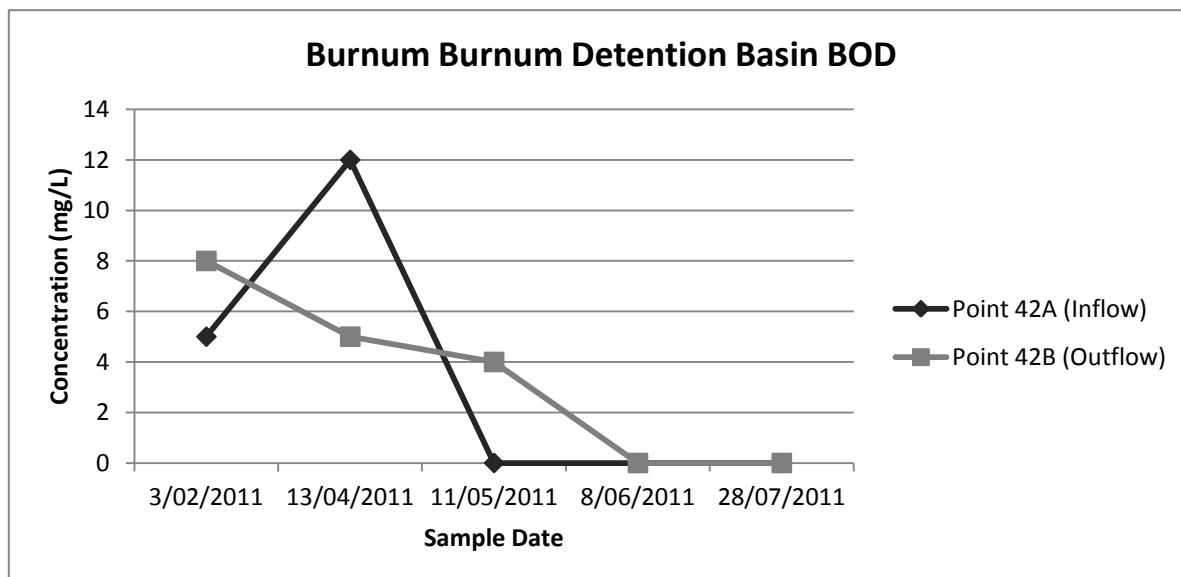


Figure 3.71 Burnum Burnum Detention Basin BOD (LOR = 2).

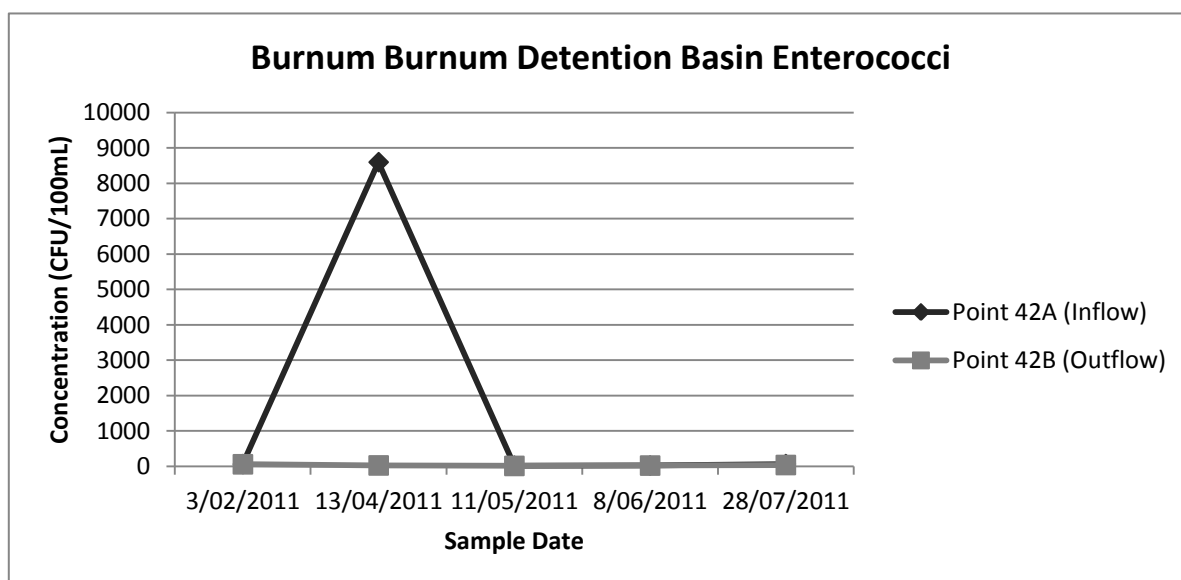


Figure 3.72 Burnum Burnum Detention Basin *Enterococci* (LOR = 1).

### 3.1.5 Gunnamatta Bay GPT

The field parameters for Gunnamatta Bay GPT (Table 3.5) indicate that there is an association between pH (Fig. 3.73), electrical conductivity (Fig. 3.74) and temperature (Fig. 3.76). Temperature is largely unchanged from the inflow to the outflow and shows a steady decrease over the sampling period. Electrical conductivity and pH are both higher at the outflow although rises and falls in the inflow values for these parameters appear to initiate corresponding changes in the outflow values. Dissolved oxygen (Fig. 3.75) also follows this pattern to a certain degree, although the association is less clearly defined. Suspended solids

(Fig. 3.77), with the exception of the first sampling event, also demonstrate a relationship between the inflow and the outflow with the outflow showing a lower concentration. Cadmium (Fig. 3.79), copper (Fig. 3.81) and zinc (Fig. 3.84) all show higher concentrations at the inflow with cadmium demonstrating a clear reduction in outflow concentrations as the inflow values fall. Copper shows a subsequent rise in outflow concentration towards the end of the sampling period as the inflow concentration rises. The outflow concentrations for zinc are largely very small, despite elevated zinc levels on 3/2/2011. Examining Figure 3.78 it can be seen that the arsenic outflow concentration was higher than the inflow for 3/2/2011 while for the rest of the sampling period it was below LOR. Chromium (Fig. 3.80) was also below the LOR for the majority of the sampling period at both the inflow and the outflow with the exception of the outflow on 28/7/2011, in which case the concentration was equal to the LOR. Lead (Fig. 3.83) and nickel (Fig. 3.82) also showed small increases above the inflow on 28/7/2011 and 8/6/2011 respectively. Lead was below the LOR at the outflow for the remainder of the sampling period despite increases in the inflow concentration. Nickel also conformed to this pattern with the exception of elevated inflow and outflow values on 3/2/2011. The relationship between the inflow and outflow values for ammonia (Fig. 3.85) is ambiguous with corresponding changes between the two, observed only occasionally. Nitrite and nitrate (Fig. 3.86), TKN (Fig. 3.87), total nitrogen (Fig. 3.88) and *Enterococci* (Fig. 3.91) all display clear relationships between the inflow and the outflow whereby the inflow concentration is higher than the outflow. BOD (Fig. 3.90) appeared to conform to this relationship also until 8/6/2011 where the outflow recorded a higher value than the inflow. Furthermore, total phosphorus (Fig. 3.89) conforms to a loose relationship in which the inflow is higher than the outflow for all but the first sampling event.

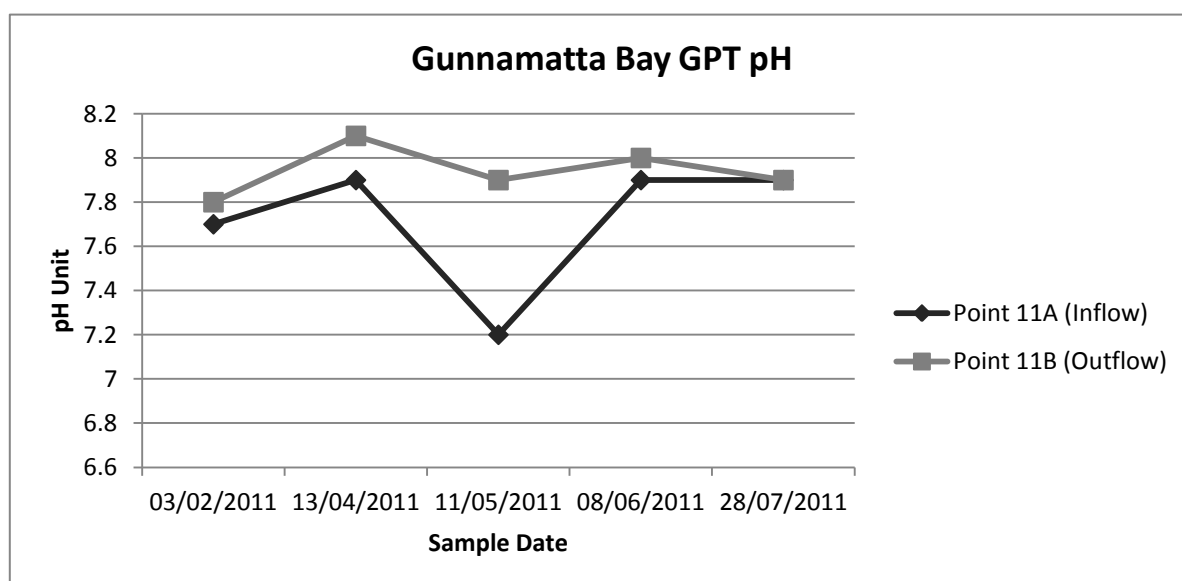


Figure 3.73 Gunnamatta Bay GPT pH (LOR = 0.1).



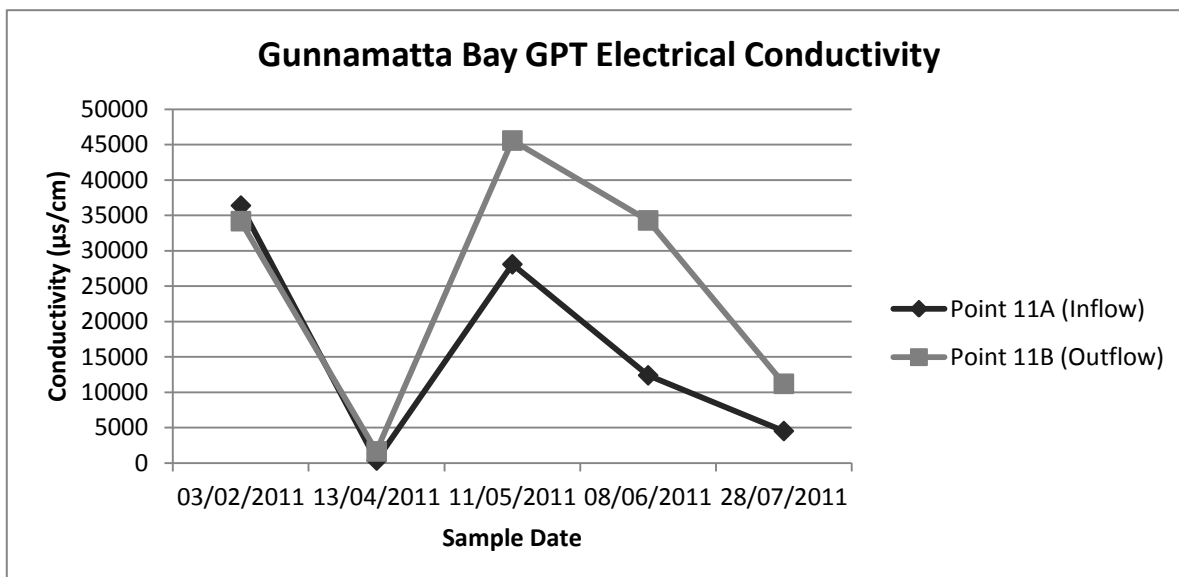


Figure 3.74 Gunnamatta Bay GPT Electrical Conductivity (LOR = 1).

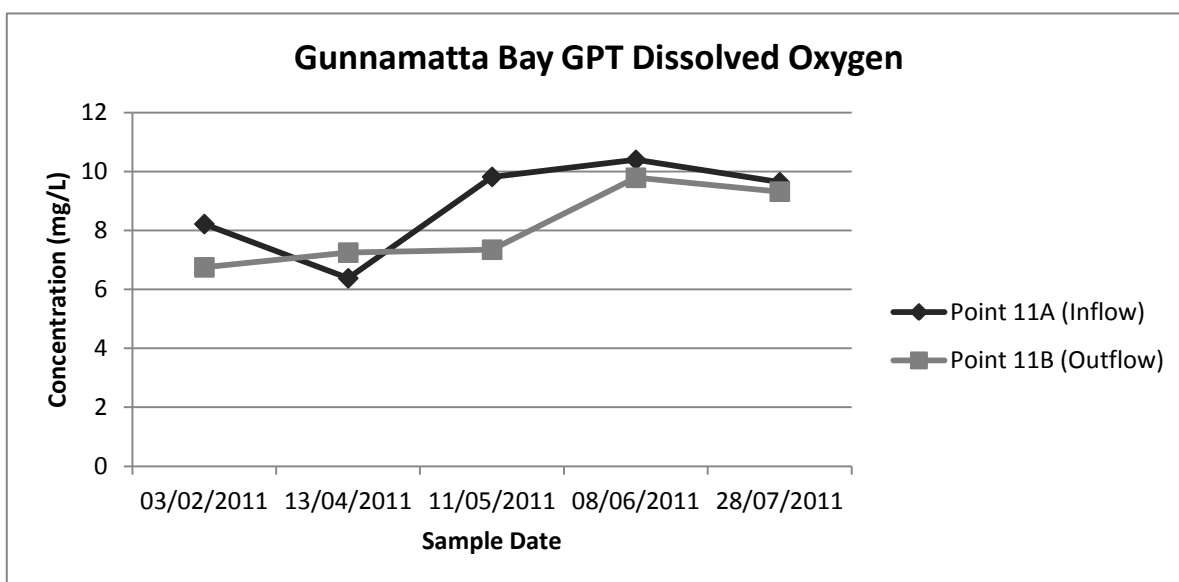


Figure 3.75 Gunnamatta Bay GPT Dissolved Oxygen (LOR = 0.01).

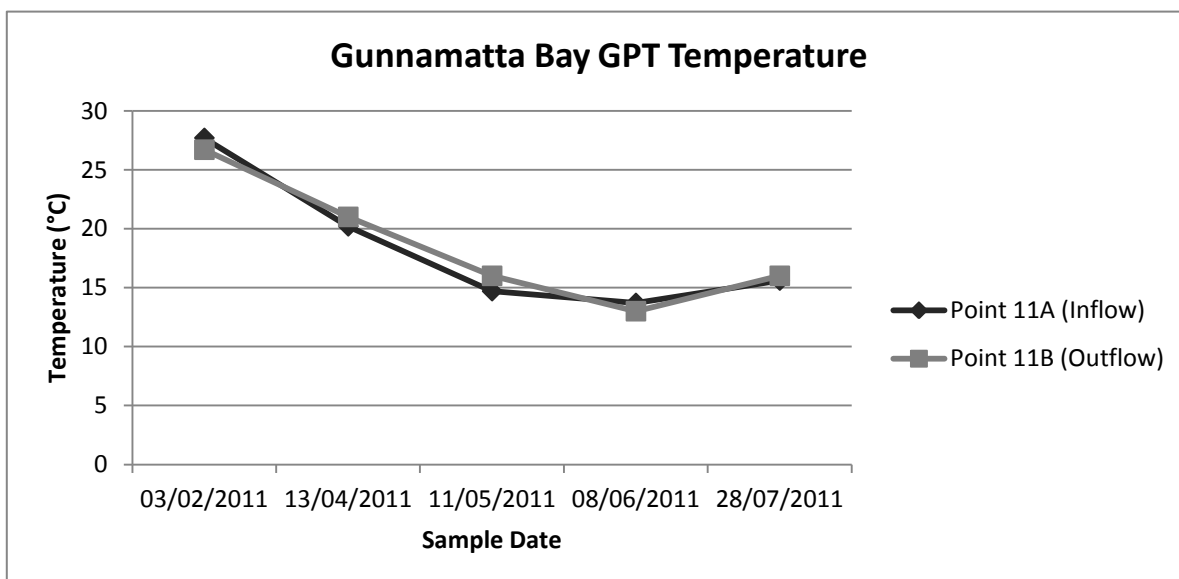


Figure 3.76 Gunnamatta Bay GPT Temperature (LOR = 0.1).

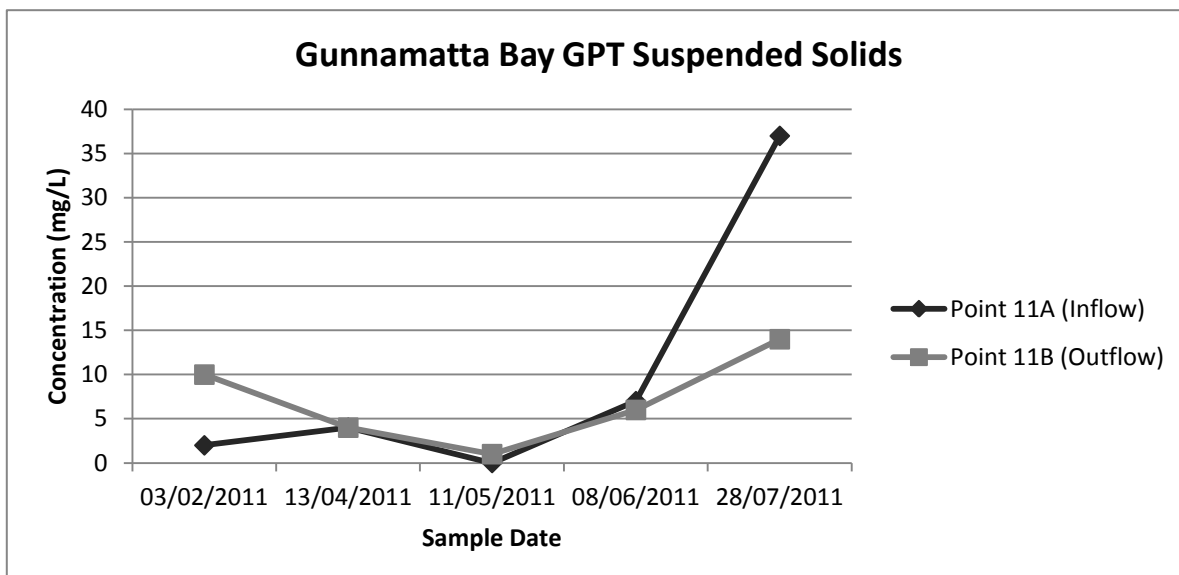


Figure 3.77 Gunnamatta Bay GPT Suspended Solids (LOR = 1).

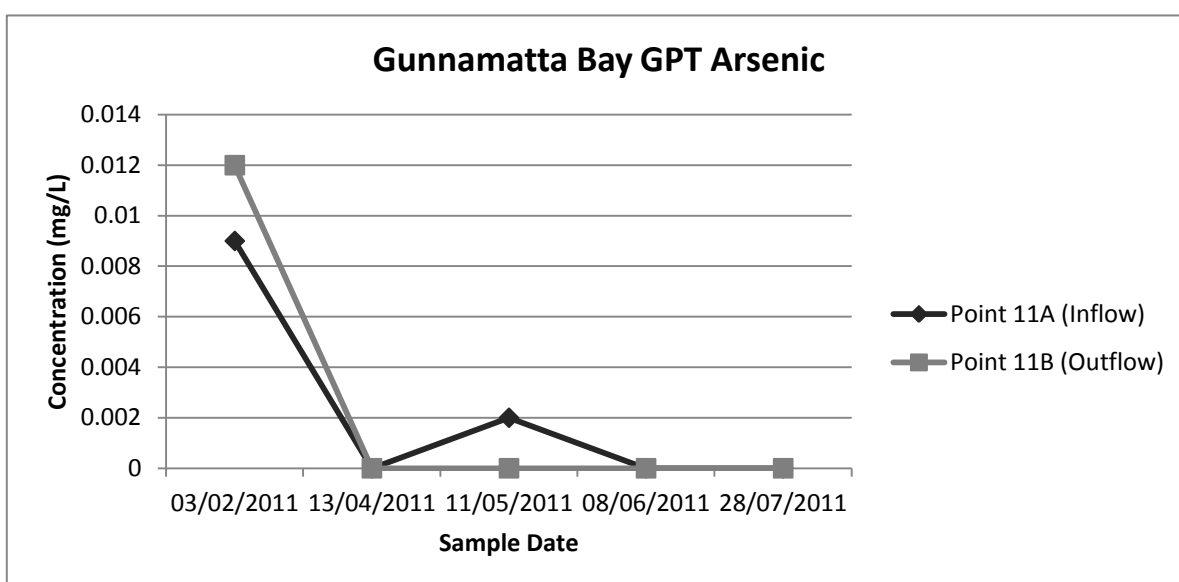


Figure 3.78 Gunnamatta Bay GPT Arsenic (LOR = 0.001).

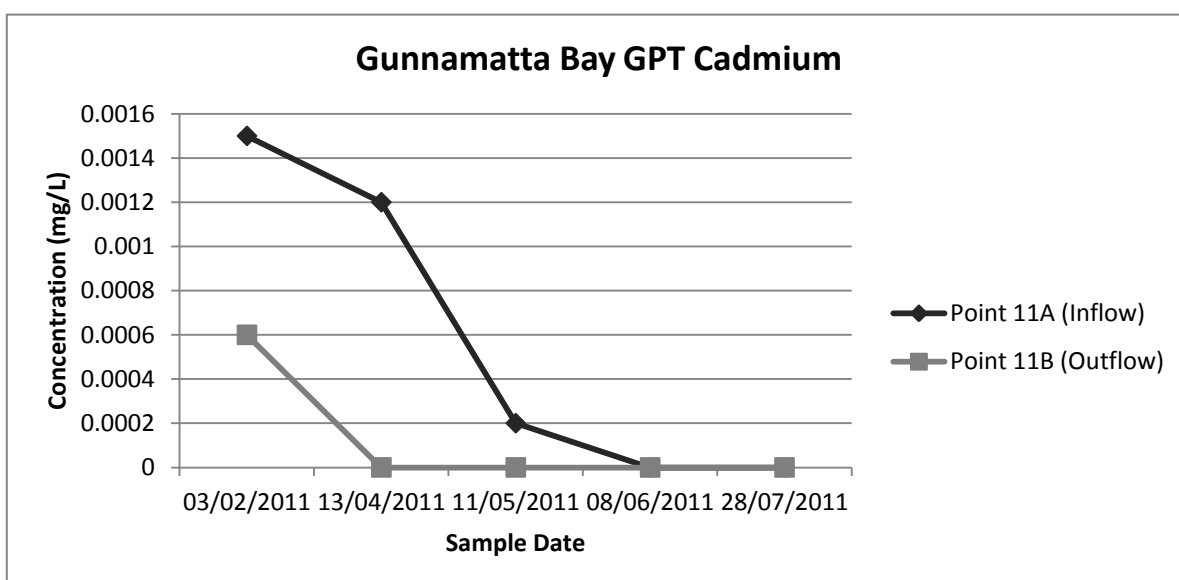


Figure 3.79 Gunnamatta Bay GPT Cadmium (LOR = 0.0001).



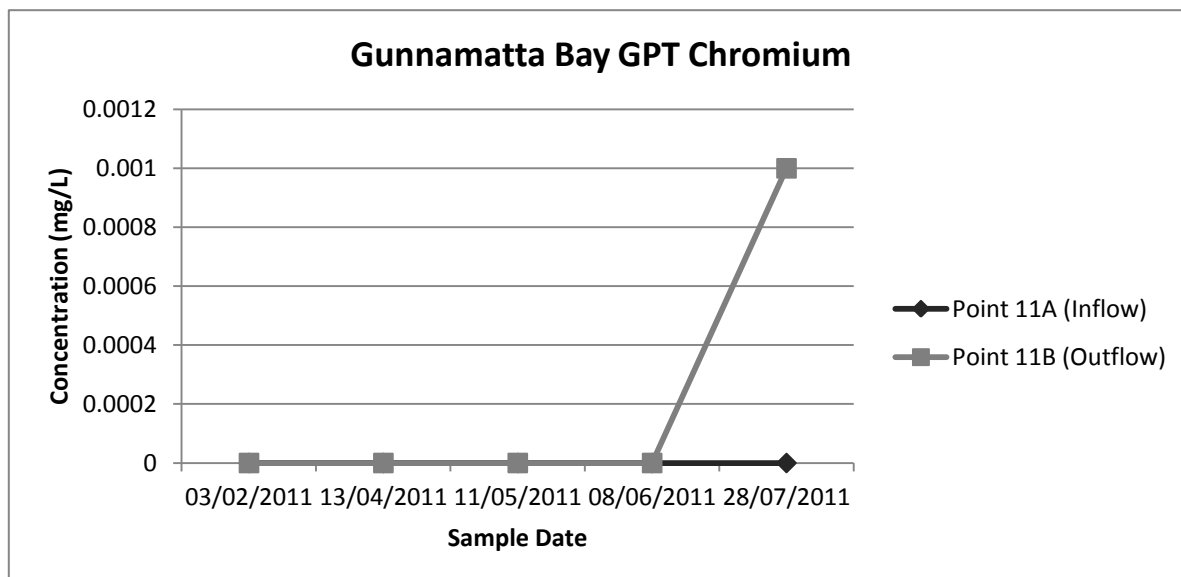


Figure 3.80 Gunnamatta Bay GPT Chromium (LOR = 0.001).

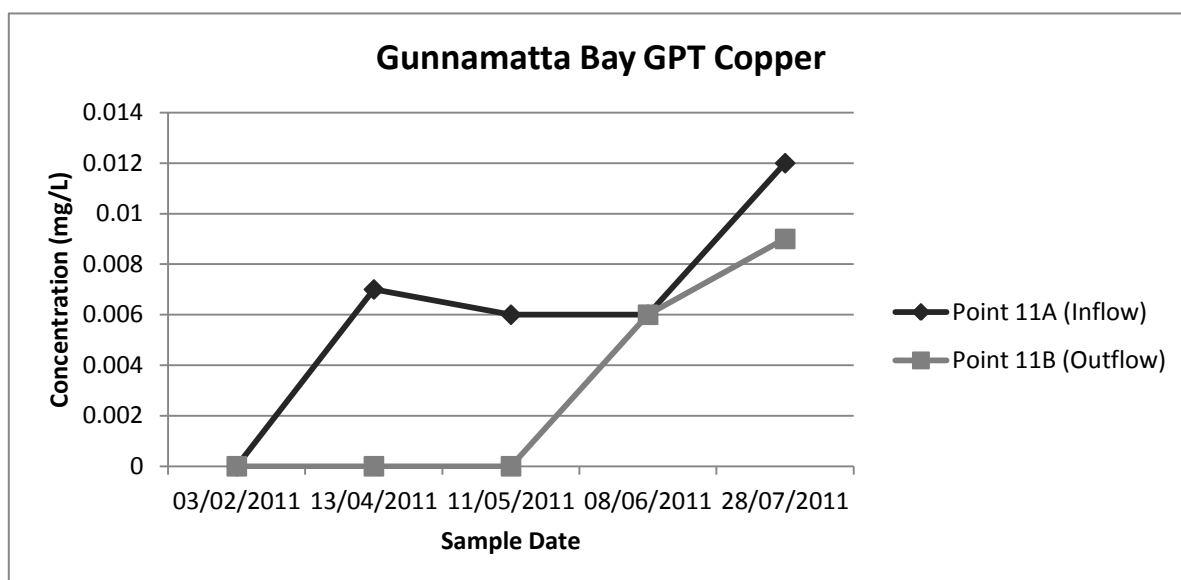


Figure 3.81 Gunnamatta Bay GPT Copper (LOR = 0.001).

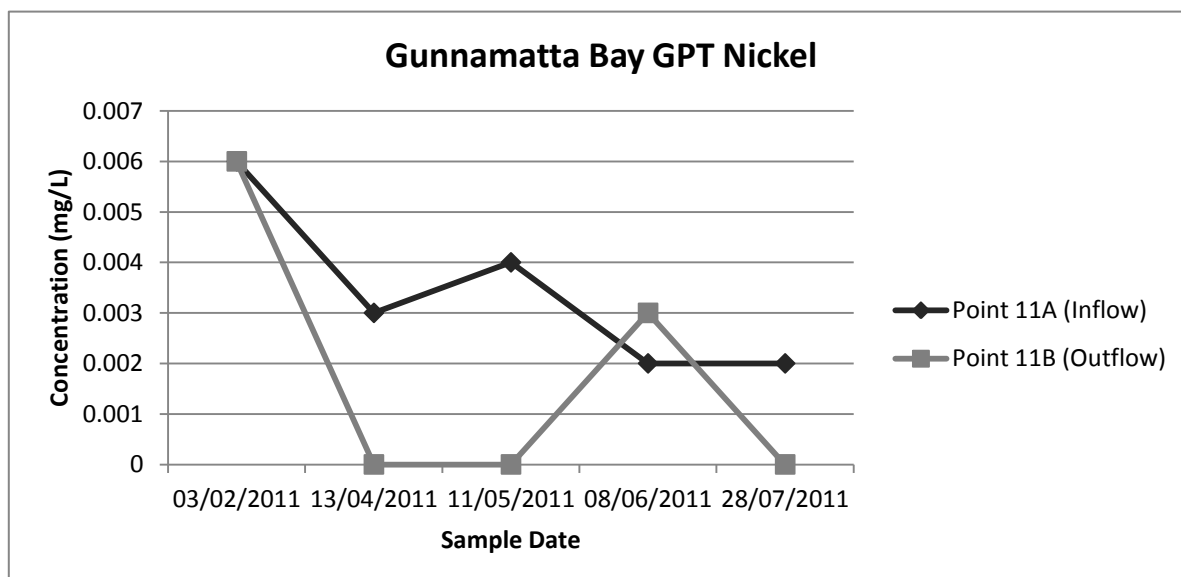


Figure 3.82 Gunnamatta Bay GPT Nickel (LOR = 0.001).

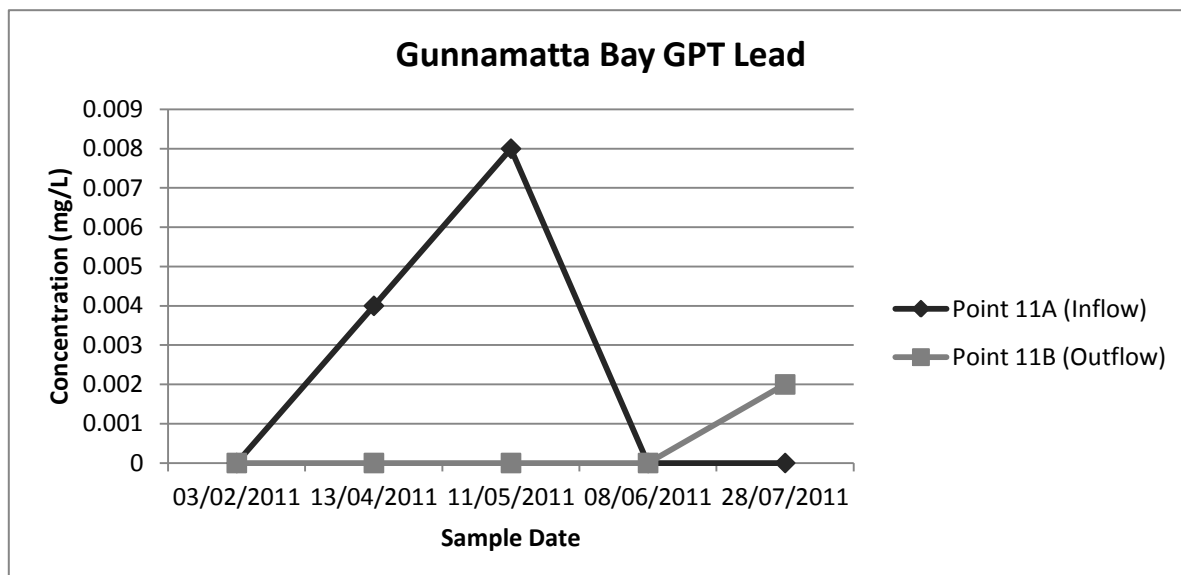


Figure 3.83 Gunnamatta Bay GPT Lead (LOR = 0.001).

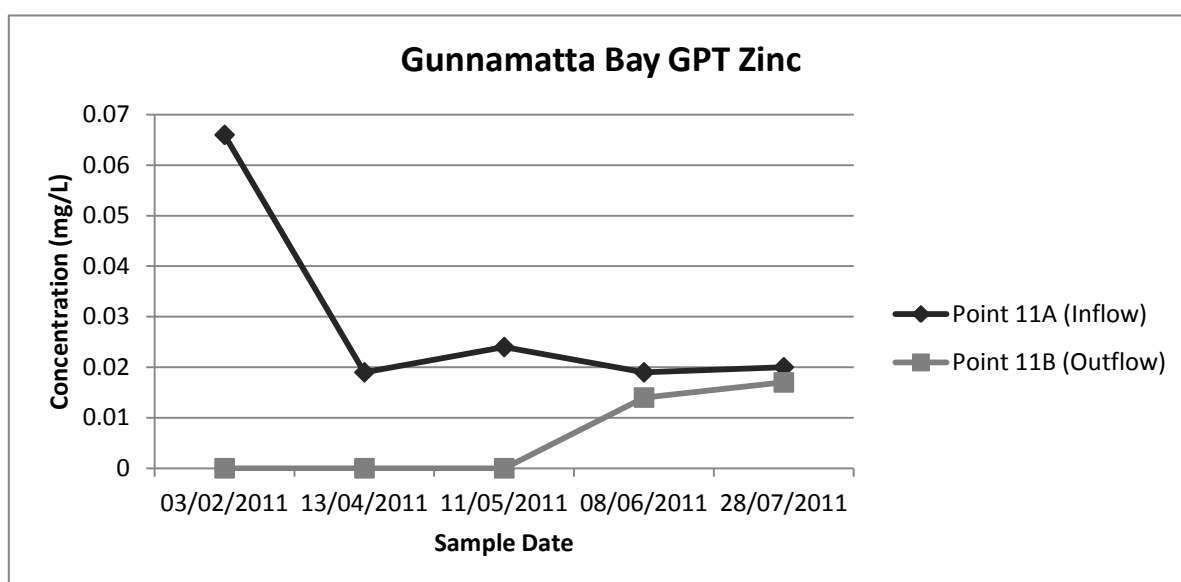


Figure 3.84 Gunnamatta Bay GPT Zinc (LOR = 0.005).

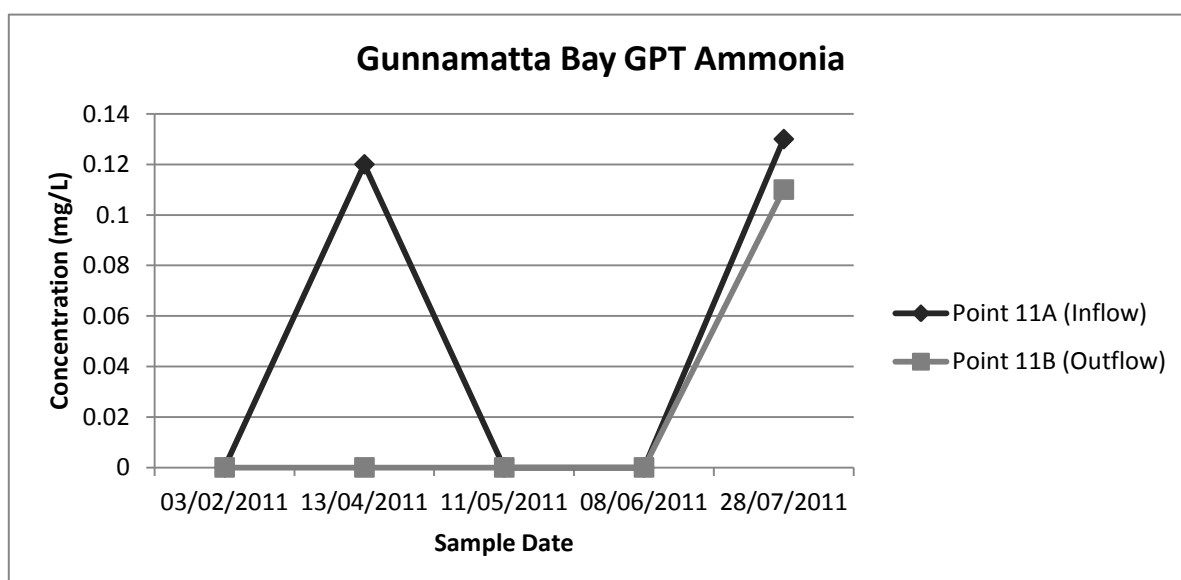


Figure 3.85 Gunnamatta Bay GPT Ammonia (LOR = 0.01).



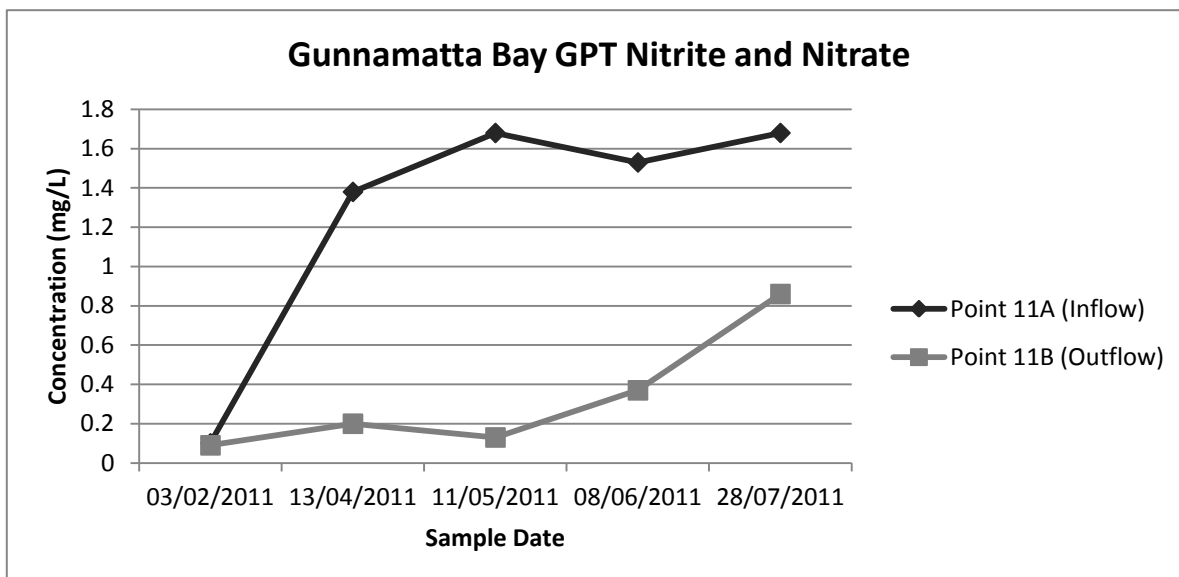


Figure 3.86 Gunnamatta Bay GPT Nitrite and Nitrate (LOR = 0.01).

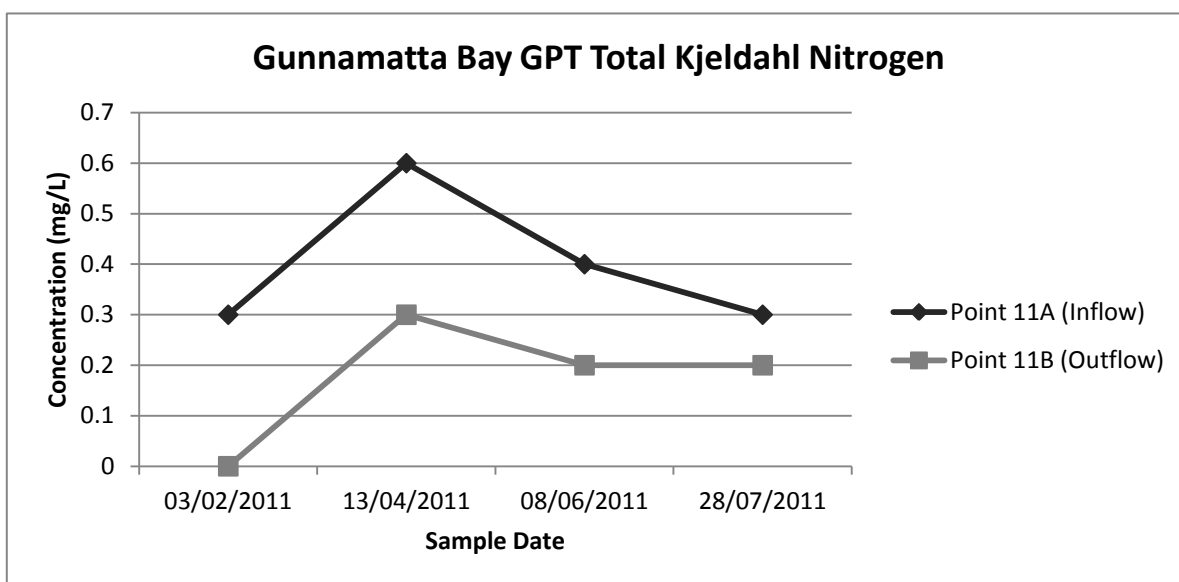


Figure 3.87 Gunnamatta Bay GPT Total Kjeldahl Nitrogen (LOR = 0.1).

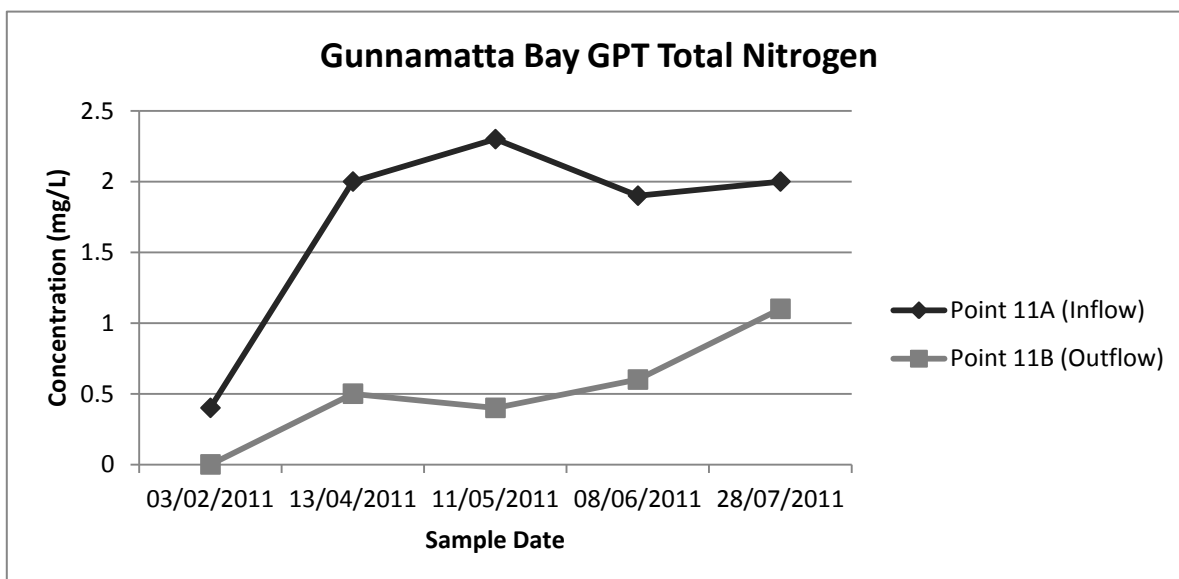


Figure 3.88 Gunnamatta Bay GPT Total Nitrogen (LOR = 0.1).

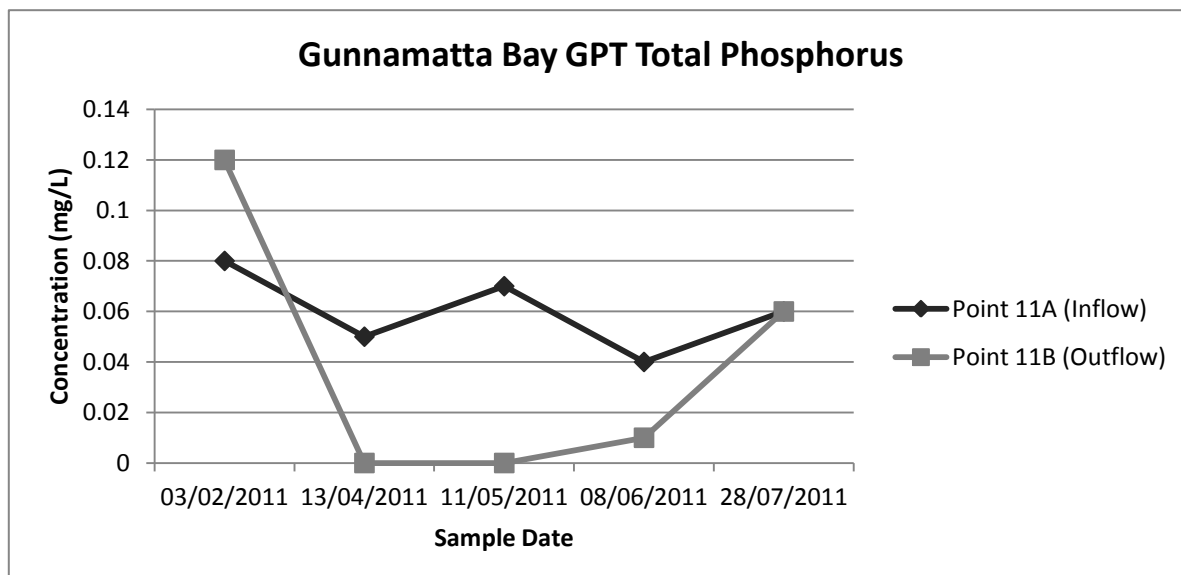


Figure 3.89 Gunnamatta Bay GPT Total Phosphorus (LOR = 0.01).

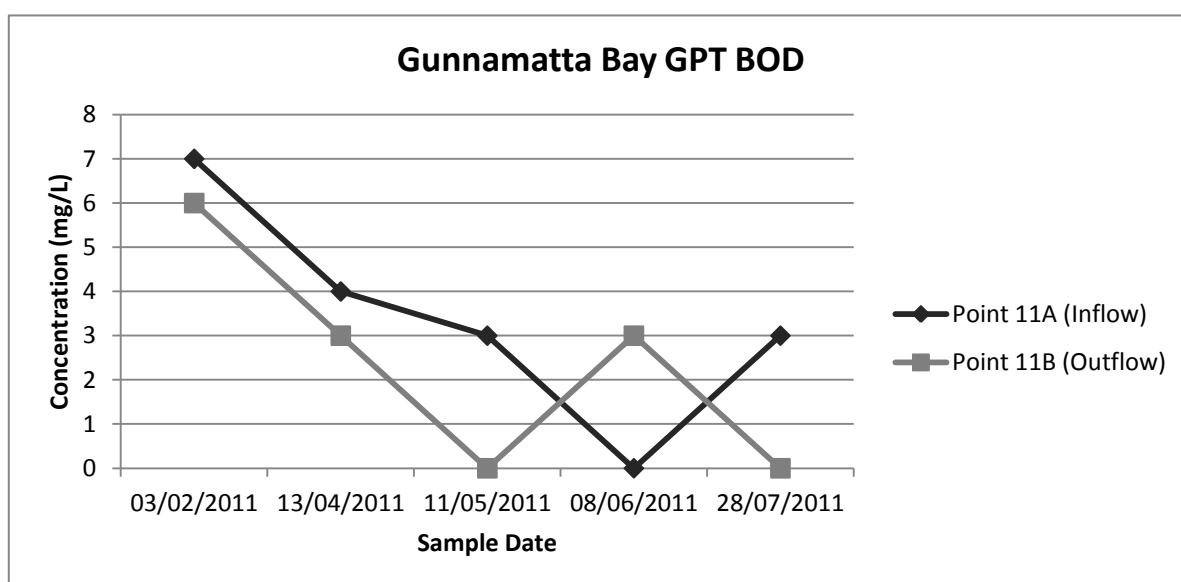


Figure 3.90 Gunnamatta Bay GPT BOD (LOR = 2).

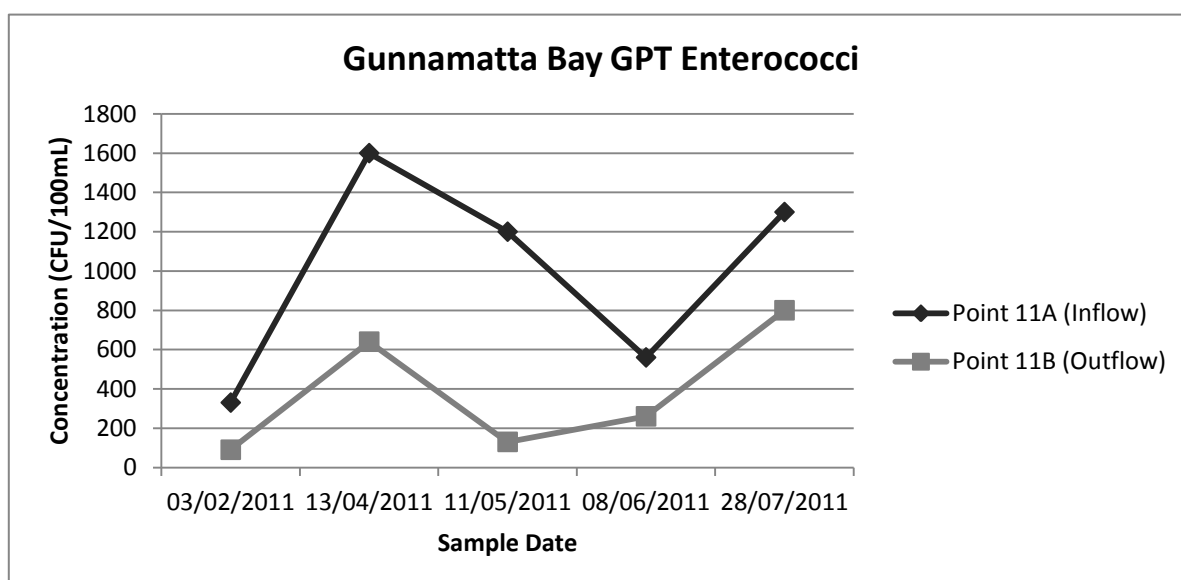


Figure 3.91 Gunnamatta Bay GPT *Enterococci* (LOR = 1).



### 3.1.6 Cronulla Beach GPT

Due to the lack of outflow data for Cronulla Beach GPT (Table 3.6) on 3/2/2011, as a result of inaccessibility on the day, the comparability of some of the parameters has been reduced. Temperature (Fig. 3.95) illustrates a relationship between the inflow and the outflow in which little change can be observed between them and a steady decrease is observed over the sampling period. Electrical conductivity (Fig. 3.93), pH (Fig. 3.92), dissolved oxygen (Fig. 3.94) and suspended solids (Fig. 3.96) do not appear to convey any clear association. Examining the metals it can be seen that arsenic (Fig. 3.97), cadmium (Fig. 3.98) and nickel (Fig. 3.101) are largely equal to or below the LOR. Small increases above the LOR can be observed on 3/2/2011 for arsenic and cadmium and 13/4/2011 for nickel. Chromium (Fig. 3.99) also conforms to this pattern, however it depicts a small increase in both inflow and outflow concentration on 28/7/2011 such that the outflow is greater than the inflow. Copper (Fig. 3.100), lead (Fig. 3.102) and zinc (Fig. 3.103) all clearly show that the inflow is greater than the outflow. Increases in outflow concentrations are seen to correspond with increases in inflow concentrations with the exception of lead on 13/4/2011, where a sharp increase in inflow concentration does not cause a subsequent increase at the outflow. In fact the outflow remains below the LOR. Finally the remaining parameters, ammonia (Fig. 3.104), nitrite and nitrate (Fig. 3.105), TKN (Fig. 3.106), total nitrogen (Fig. 3.107), total phosphorus (Fig. 3.108), BOD (Fig. 3.109) and *Enterococci* (Fig. 3.110) all demonstrate that the inflow concentration is higher than the outflow. Changes in the inflow concentration do, in the majority of instances, correspond with changes in the outflow concentration.

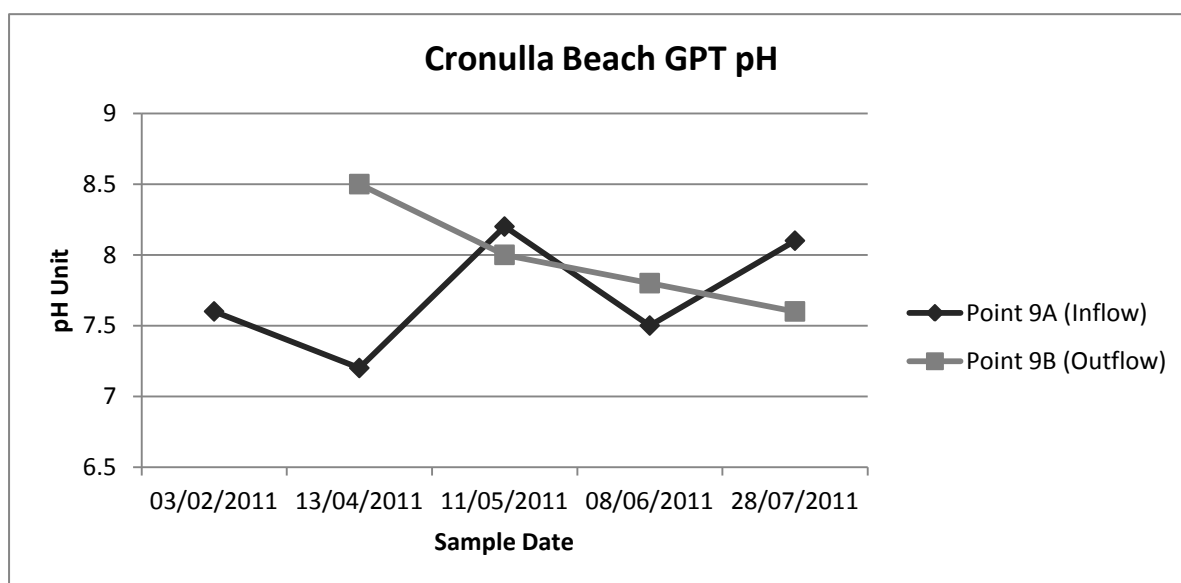


Figure 3.92 Cronulla Beach GPT pH (LOR = 0.1).

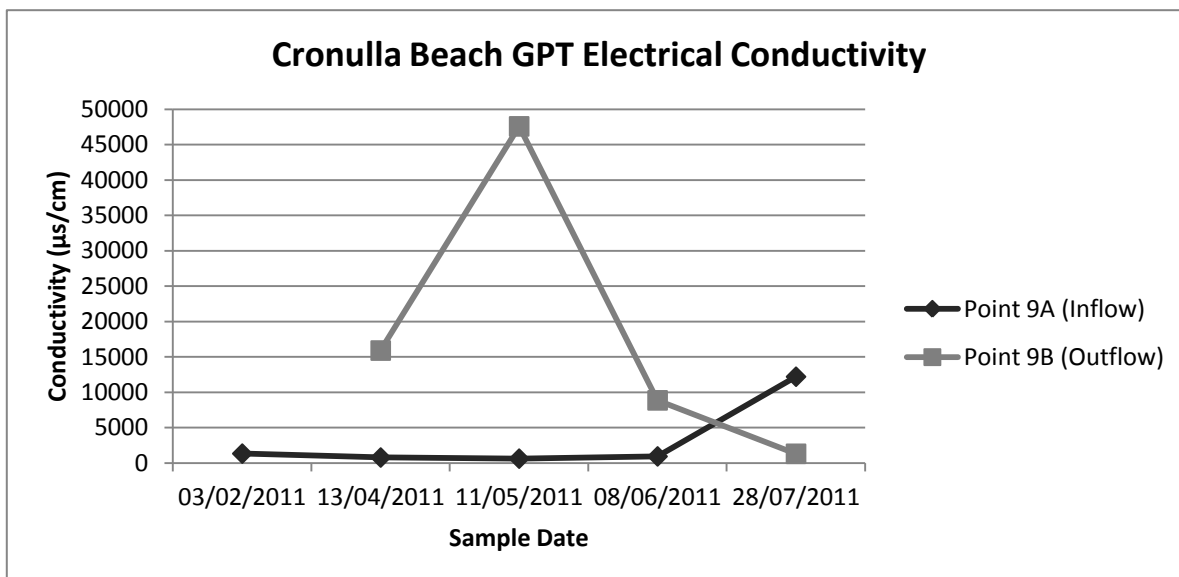


Figure 3.93 Cronulla Beach GPT Electrical Conductivity (LOR = 1).

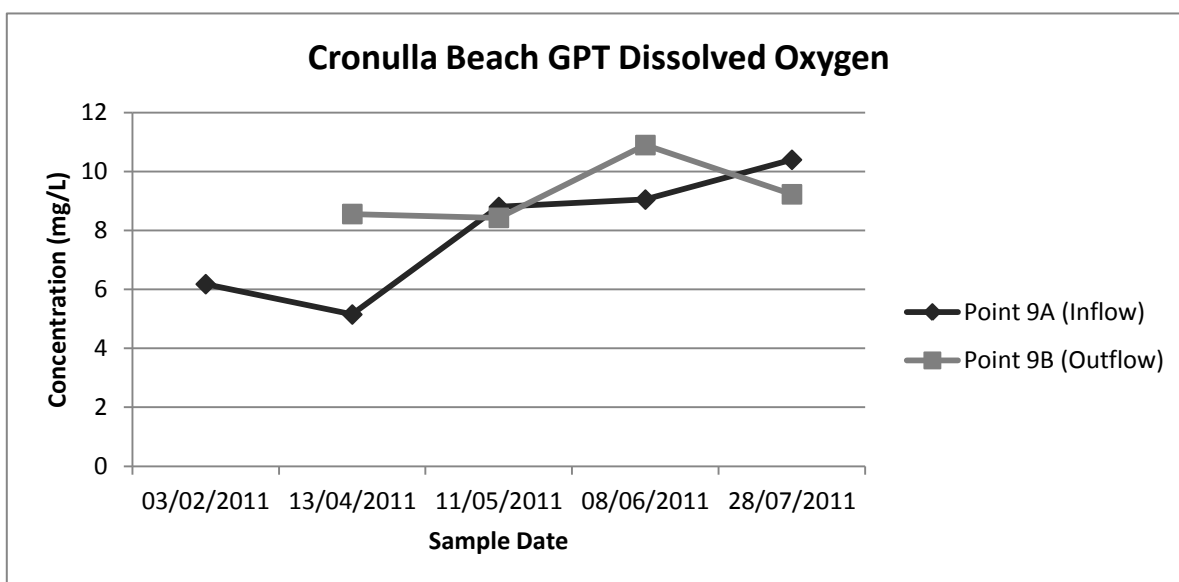


Figure 3.94 Cronulla Beach GPT Dissolved Oxygen (LOR = 0.01).

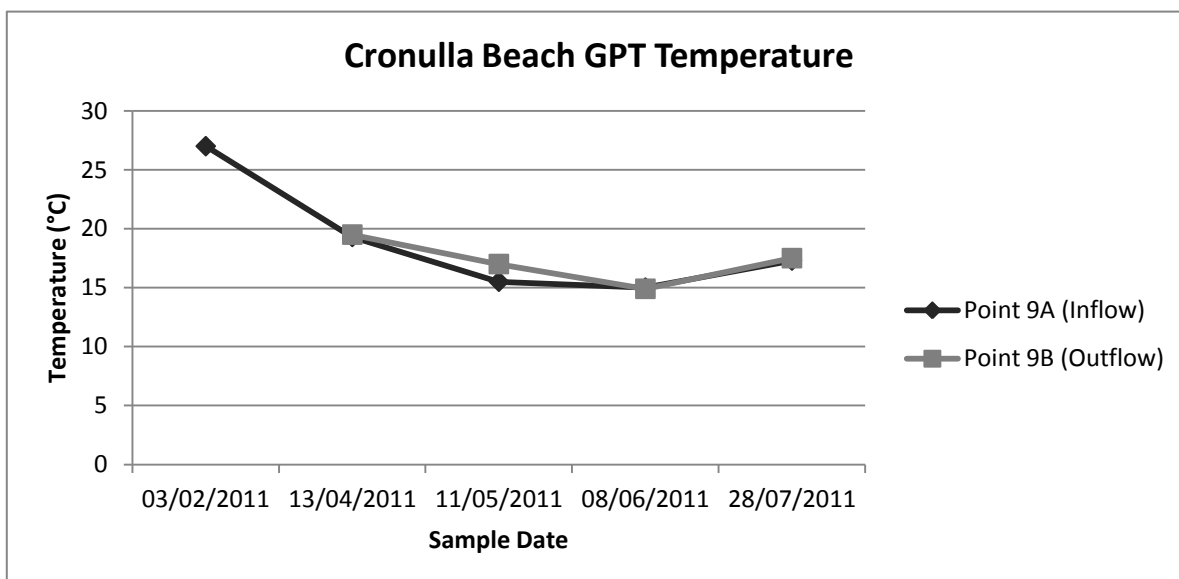


Figure 3.95 Cronulla Beach GPT Temperature (LOR = 0.1).



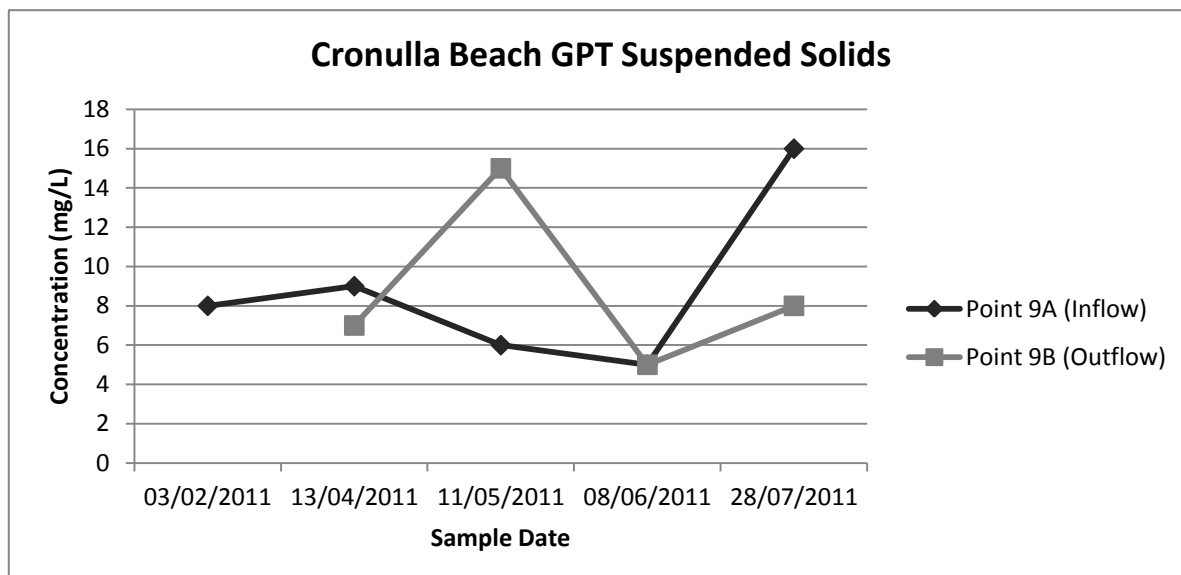


Figure 3.96 Cronulla Beach GPT Suspended Solids (LOR = 1).

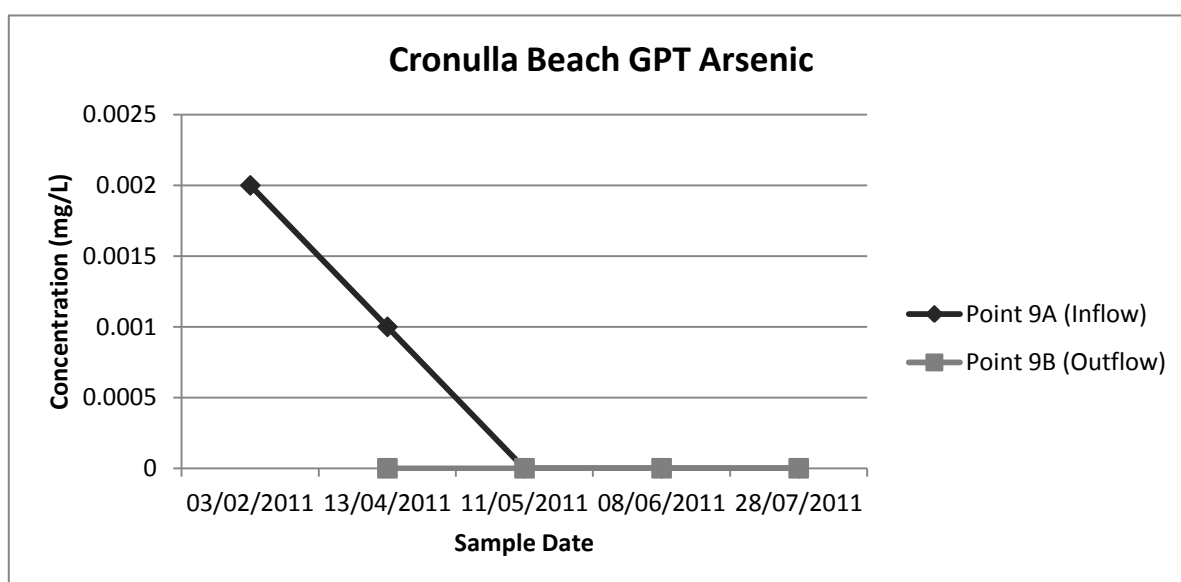


Figure 3.97 Cronulla Beach GPT Arsenic (LOR = 0.001).

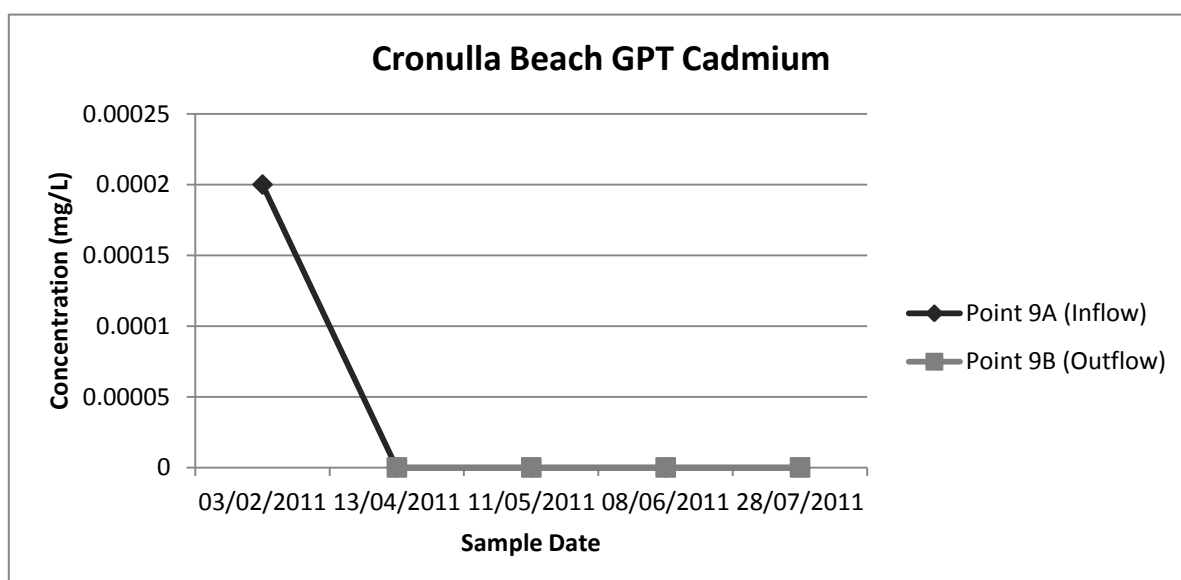


Figure 3.98 Cronulla Beach GPT Cadmium (LOR = 0.0001).

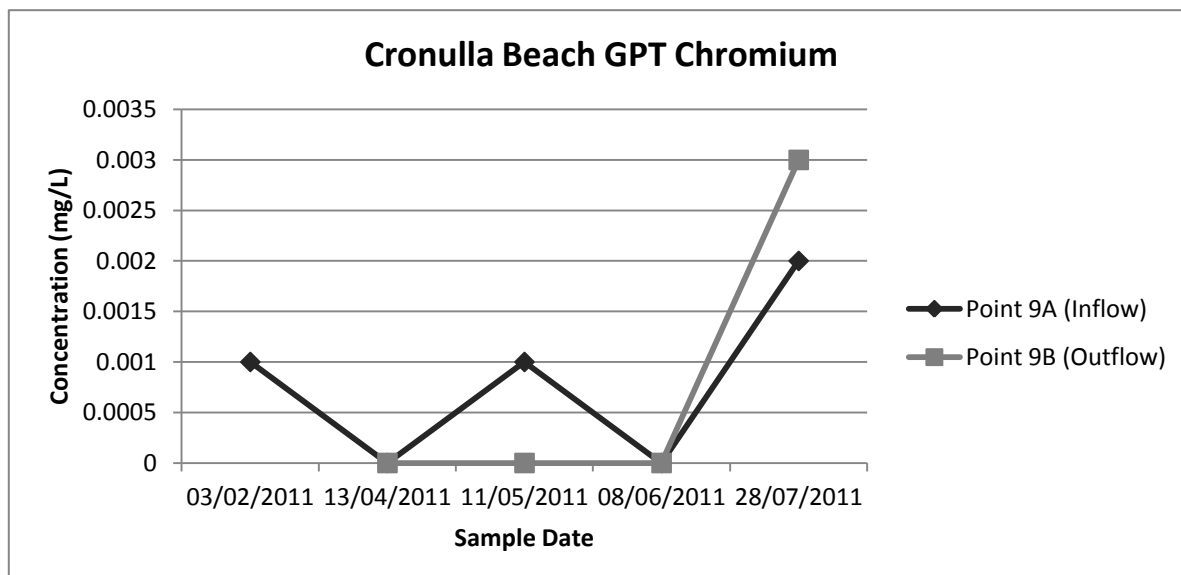


Figure 3.99 Cronulla Beach GPT Chromium (LOR = 0.001).

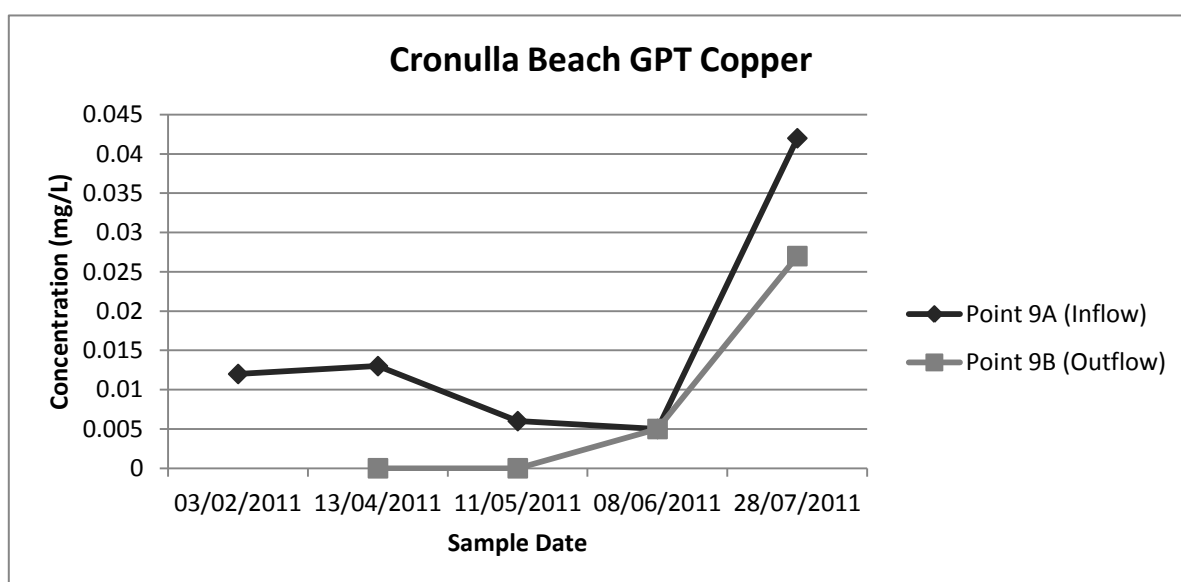


Figure 3.100 Cronulla Beach GPT Copper (LOR = 0.001).

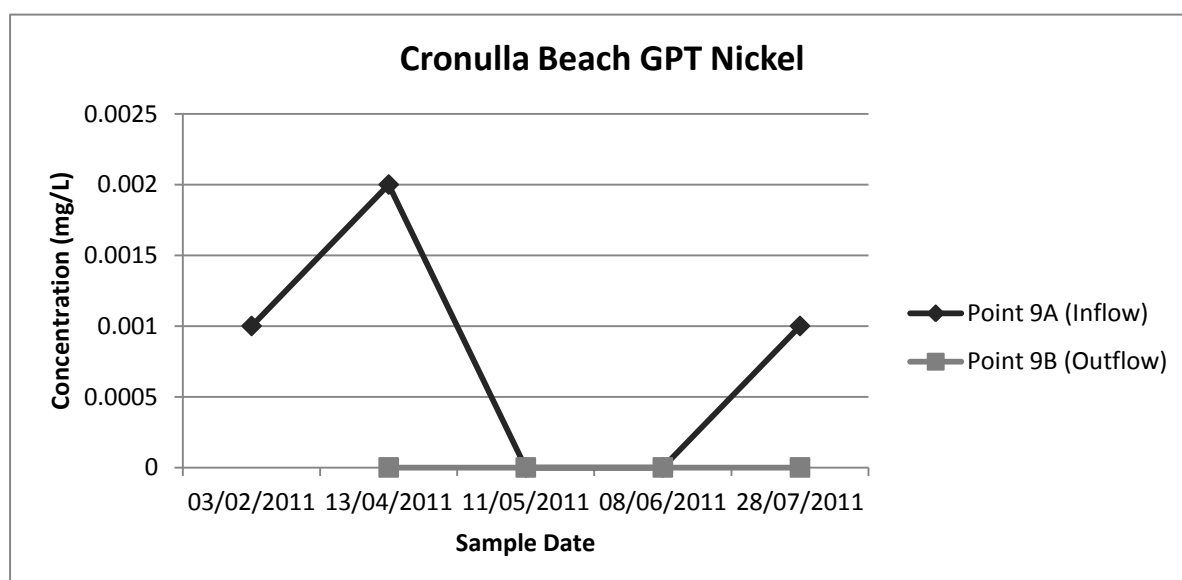


Figure 3.101 Cronulla Beach GPT Nickel (LOR = 0.001).



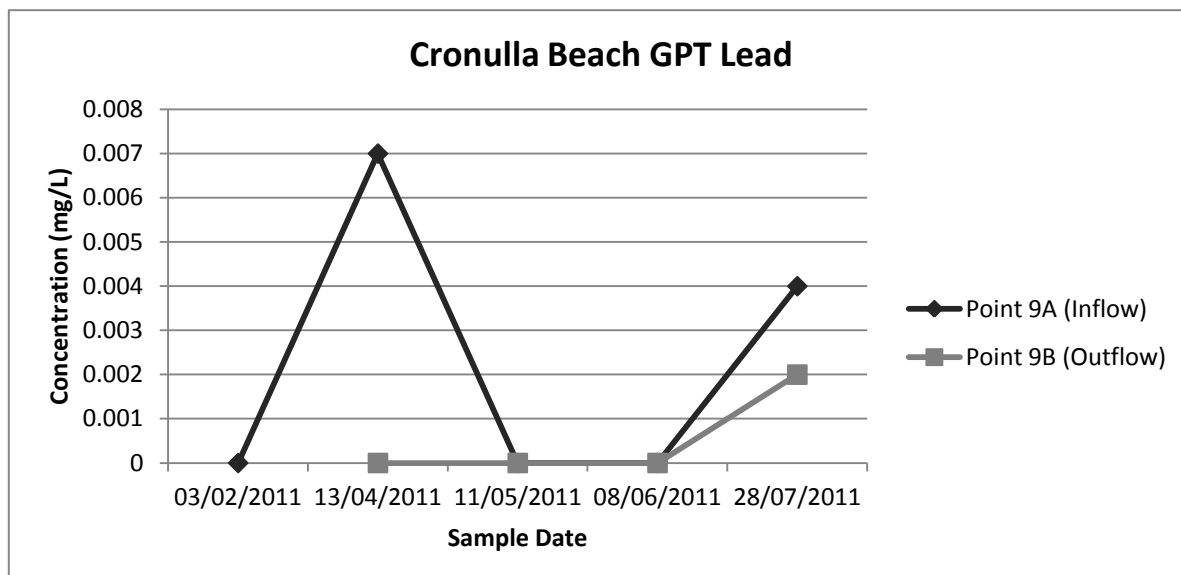


Figure 3.102 Cronulla Beach GPT Lead (LOR = 0.001).

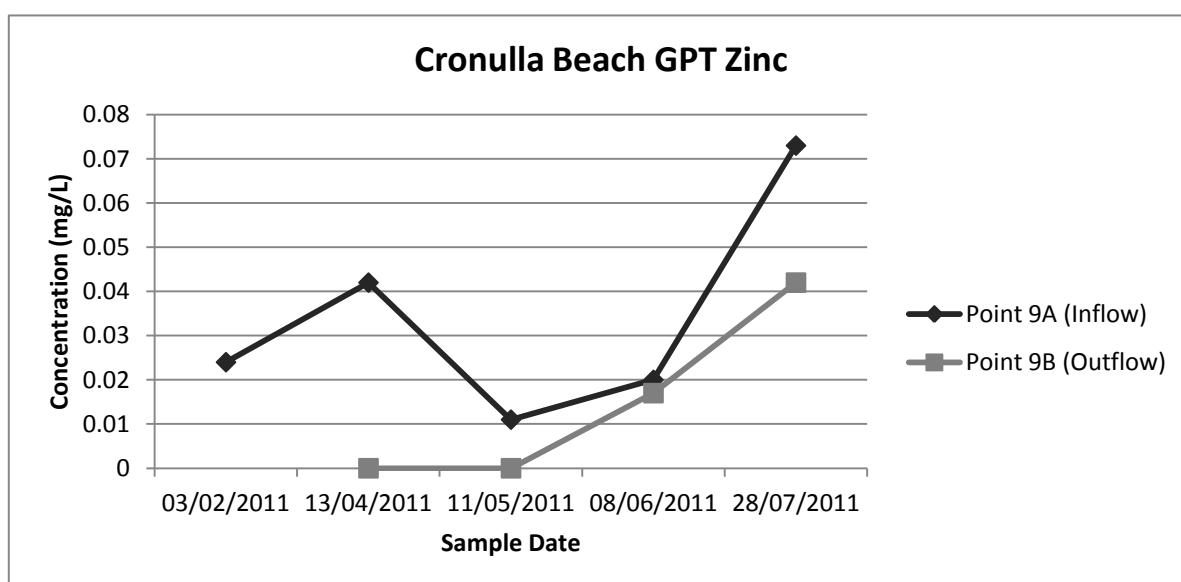


Figure 3.103 Cronulla Beach GPT Zinc (LOR = 0.005).

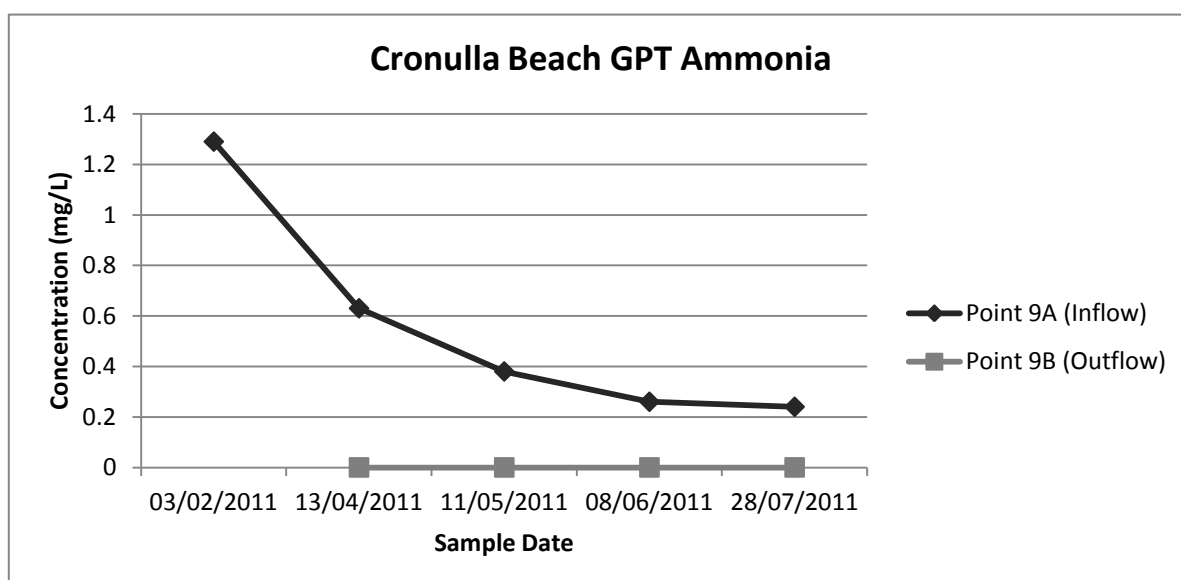


Figure 3.104 Cronulla Beach GPT Ammonia (LOR = 0.01).

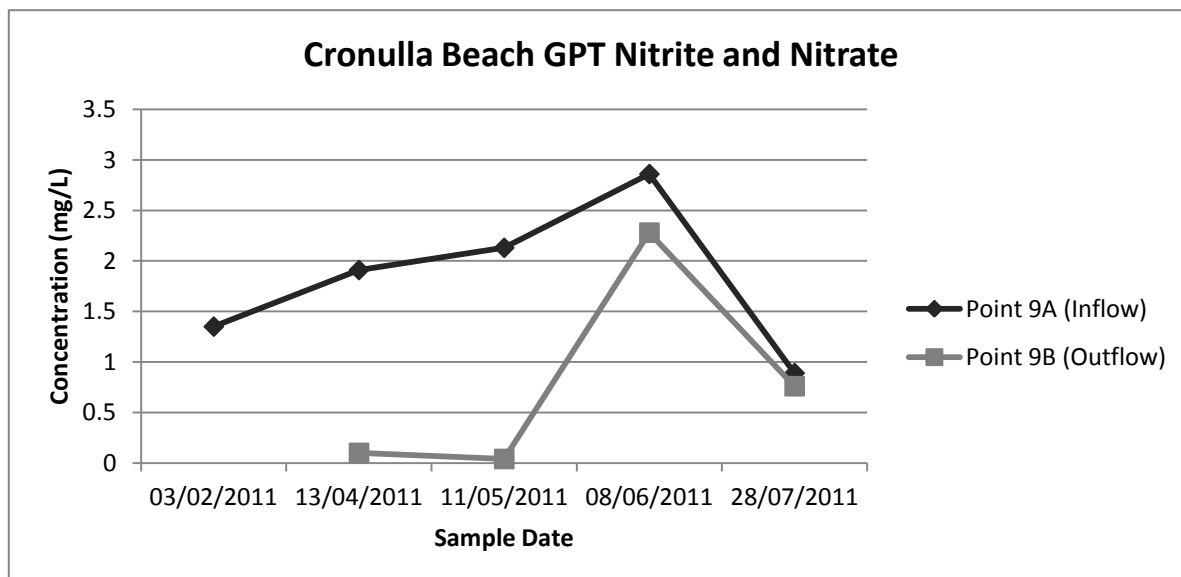


Figure 3.105 Cronulla Beach GPT Nitrite and Nitrate (LOR = 0.01).

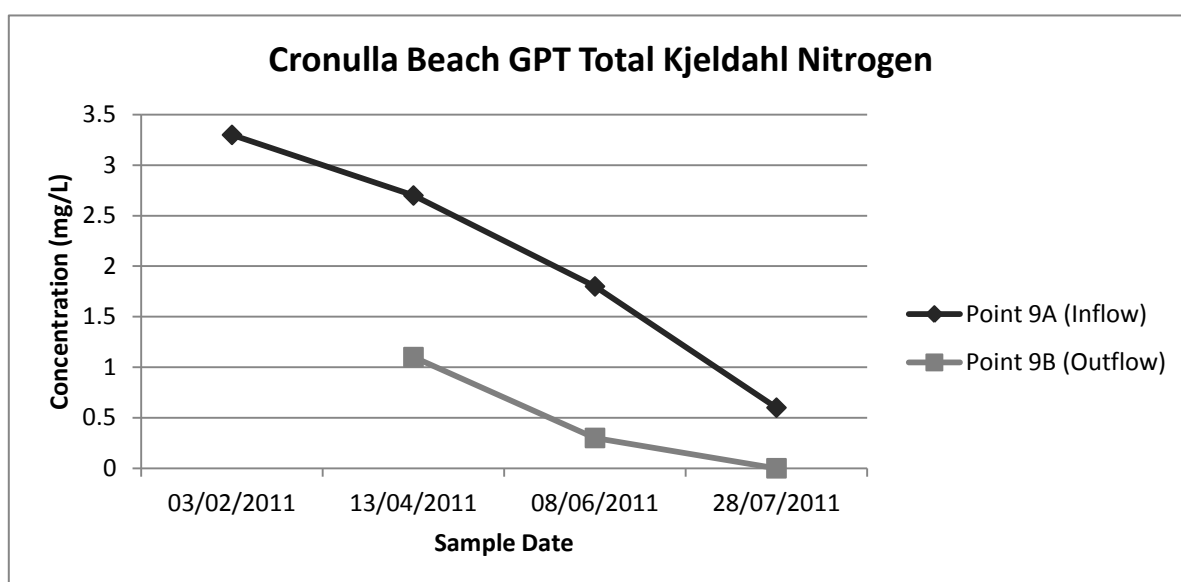


Figure 3.106 Cronulla Beach GPT Total Kjeldahl Nitrogen (LOR = 0.1).

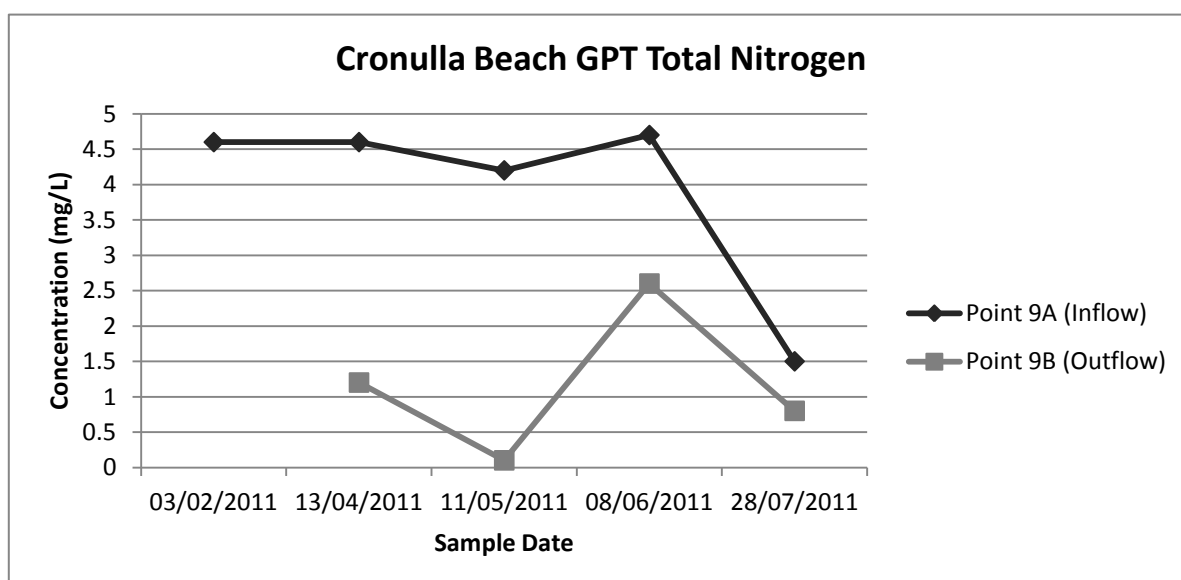


Figure 3.107 Cronulla Beach GPT Total Nitrogen (LOR = 0.1).



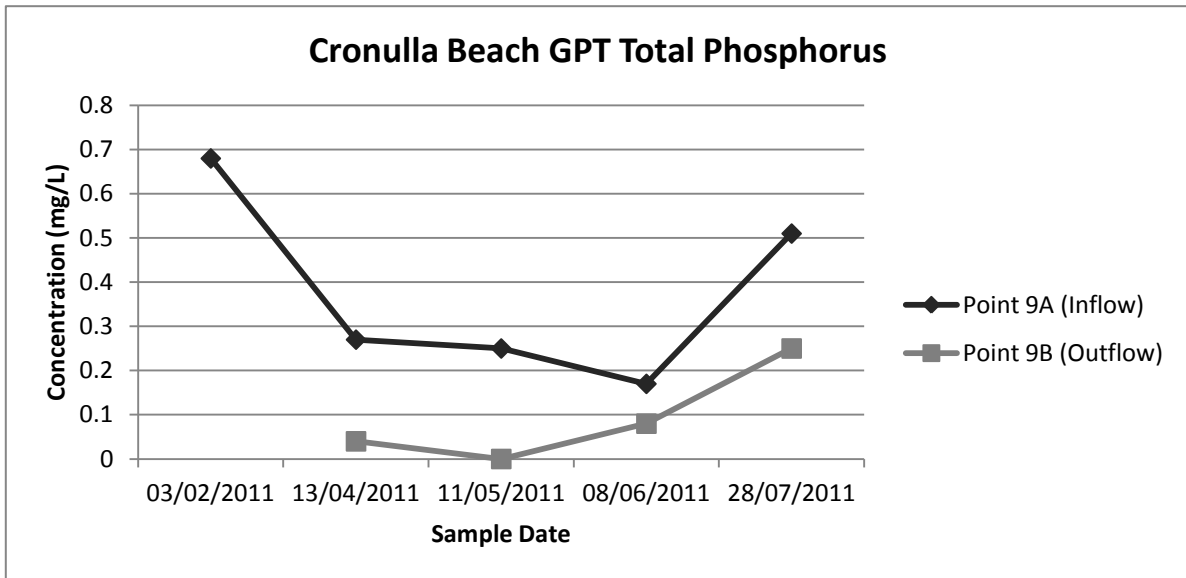


Figure 3.108 Cronulla Beach GPT Total Phosphorus (LOR = 0.01).

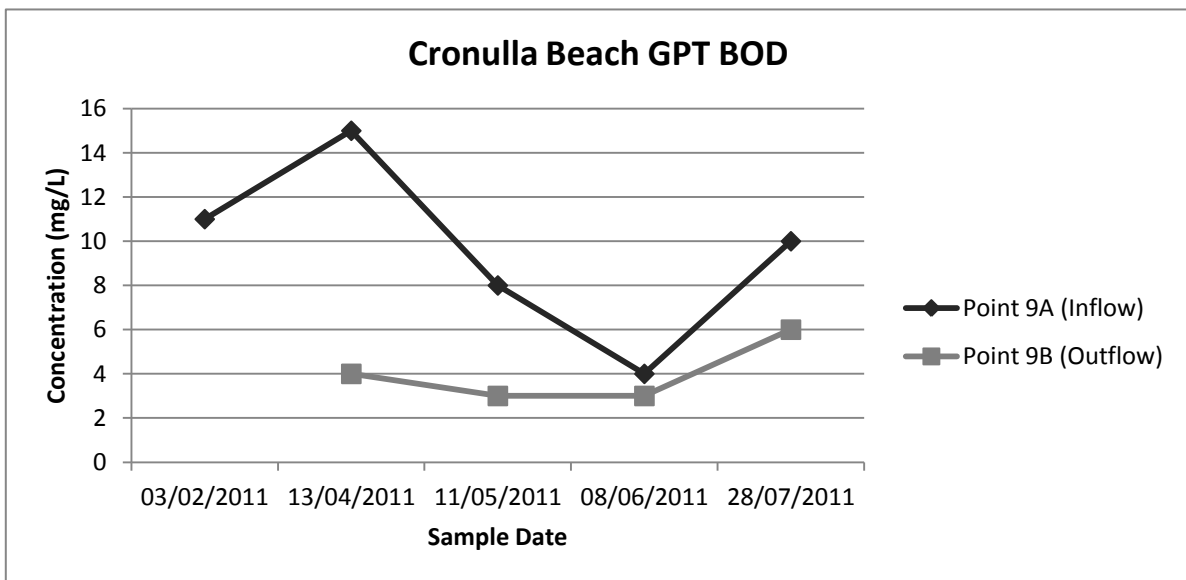


Figure 3.109 Cronulla Beach GPT BOD (LOR = 2).

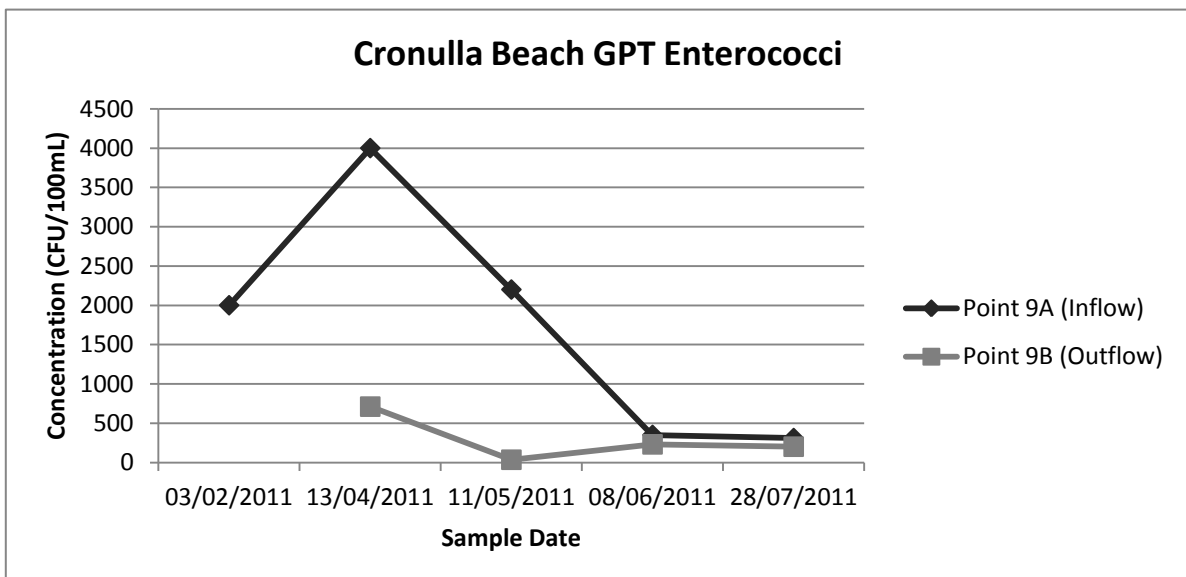


Figure 3.110 Cronulla Beach GPT *Enterococci* (LOR = 1).

Table 3.1 Mianga Avenue Wetland Water Quality Data.

| ALS Workgroup Number  |           |                                     |   |   |   | EW1100422          | EW1100422           | ES1107703                      | ES1107703                      | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223  | EW1102223  |
|---|-----------|-------------------------------------|---|---|---|--------------------|---------------------|--------------------------------|--------------------------------|--------------------|---------------------|--------------------|---------------------|--|--|
| Sample Date   |           |                                     |   |   |   | 03/02/2011         | 03/02/2011          | 13/04/2011                     | 13/04/2011                     | 11/05/2011         | 11/05/2011          | 08/06/2011         | 08/06/2011          | 28/07/2011   | 28/07/2011   |
| Sampling Site   |           |                                     |   |   |   | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow)             | Point 22B (Outflow)            | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow)                                   | Point 22B (Outflow)                                  |
| Rainfall Audley (Royal National Park) 3.5km away <sup>B</sup> |           |                                     |   |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 6mm 11/4/2011,<br>1mm 8/4/2011 | 6mm 11/4/2011,<br>1mm 8/4/2011 | 2mm 10/5/2011      | 2mm 10/5/2011       | 2mm 3/6/2011       | 2mm 3/6/2011        | 4mm 27/7/2011,<br>1mm 26/7/2011,<br>41mm 23/7/2011   | 4mm 27/7/2011,<br>1mm 26/7/2011,<br>41mm 23/7/2011   |
| Rainfall Lucas Heights (ANSTO) 4.2km away <sup>B</sup>        |           |                                     |   |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 6.8mm 11/4/2011                | 6.8mm 11/4/2011                | 0mm 5 days prior   | 0mm 5 days prior    | 0.6mm 3/6/2011     | 0.6mm 3/6/2011      | 1.4mm 27/7/2011,<br>1mm 26/7/2011,<br>36mm 23/7/2011 | 1.4mm 27/7/2011,<br>1mm 26/7/2011,<br>36mm 23/7/2011 |
|   | Units     | Laboratory Limit of Reporting (LOR) | Port Hacking River Catchment Control Site Kangaroo Creek <sup>F</sup> | Australian Runoff Quality Guidelines (2006) | ANZECC Protection of Aquatic Ecosystems Guidelines 95% (2000) |                    |                     |                                |                                |                    |                     |                    |                     |  |  |
| pH  | pH Unit   | 0.1                                 | 7.5   | NE <sup>D</sup>                             | 6.5 - 8.0 <sup>A</sup>  | -                  | 7.3                 | 7.3                            | 7.4                            | 6.8                | 7.2                 | 7.4                | 7.3                 | 7.8  | 7.6  |
| Electrical Conductivity (NC)                                  | µS/cm     | 1                                   | 240   | NE <sup>D</sup>                             | NE <sup>D</sup>   | -                  | 140                 | 287                            | 80                             | 315                | 115                 | 422                | 127                 | 392  | 157  |
| Dissolved Oxygen  | mg/L      | 0.01                                | 5.8   | NE <sup>D</sup>                             | NE <sup>D</sup>   | -                  | 8.77                | 3.97                           | 7.59                           | 11.3               | 7.13                | 11.1               | 9.52                | 11.7   | 11   |
| Temperature   | °C        | 0.1                                 | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | -                  | 27.4                | 16.5                           | 17                             | 14.3               | 11.8                | 14.3               | 11.5                | 13.4   | 11.9   |
| Suspended Solids (SS)   | mg/L      | 1                                   | 2   | 25  | NE <sup>D</sup>   | -                  | 15                  | 5                              | 19                             | 18                 | 10                  | 10                 | <1                  | 6  | 2  |
| Arsenic   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | NE <sup>D</sup>                             | 0.024   | -                  | <0.001              | <0.001                         | <0.001                         | <0.001             | <0.001              | <0.001             | <0.001              | <0.001   | <0.001   |
| Cadmium   | mg/L      | 0.0001                              | NE <sup>D</sup>   | 0.0004                                      | 0.0002  | -                  | 0.0015              | <0.0001                        | 0.0066                         | 0.0001             | <0.0001             | <0.0001            | <0.0001             | <0.0001  | <0.0001  |
| Chromium  | mg/L      | 0.001                               | NE <sup>D</sup>   | 0.01  | NE <sup>D</sup>   | -                  | <0.001              | <0.001                         | <0.001                         | <0.001             | <0.001              | <0.001             | <0.001              | 0.001  | <0.001   |
| Copper  | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | 0.01  | 0.0014  | -                  | 0.003               | 0.007                          | 0.002                          | 0.003              | 0.003               | 0.015              | 0.003               | 0.01   | 0.003  |
| Nickel  | mg/L      | 0.001                               | NE <sup>D</sup>   | NE <sup>D</sup>                             | 0.011   | -                  | <0.001              | <0.001                         | <0.001                         | <0.001             | <0.001              | 0.002              | <0.001              | 0.001  | <0.001   |
| Lead  | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | 0.025                                       | 0.0034  | -                  | 0.003               | 0.002                          | <0.001                         | <0.001             | 0.003               | 0.006              | <0.001              | 0.002  | <0.001   |
| Zinc  | mg/L      | 0.005                               | 0.005   | 0.05  | 0.008   | -                  | 0.035               | 0.2                            | 0.066                          | 0.089              | 0.097               | 0.154              | 0.084               | 0.138  | 0.093  |
| Ammonia as N  | mg/L      | 0.01                                | 0.005 <sup>E</sup>  | NE <sup>D</sup>                             | 0.9   | -                  | 0.23                | 0.09                           | <0.01                          | 0.03               | 0.06                | 0.07               | 0.06                | 0.05   | 0.12   |
| Nitrite + Nitrate as N  | mg/L      | 0.01                                | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | -                  | 0.03                | 1.4                            | 0.05                           | 3.74               | 0.27                | 2.8                | 0.15                | 3.2  | 0.26   |
| Total Kjeldahl Nitrogen as N                                  | mg/L      | 0.1                                 | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | -                  | 1.7                 | 1.5                            | 1.7                            | -                  | -                   | 1.3                | 0.1                 | <0.1   | 0.3  |
| Total Nitrogen as N   | mg/L      | 0.1                                 | 0.2   | 0.5   | 0.5 <sup>A</sup>  | -                  | 1.7                 | 2.9                            | 1.8                            | 5.2                | 0.6                 | 4.1                | 0.2                 | 3.2  | 0.6  |
| Total Phosphorus as P   | mg/L      | 0.01                                | 0.005 <sup>E</sup>  | 0.05  | 0.05 <sup>A</sup>   | -                  | <0.01               | 0.06                           | 0.08                           | 0.13               | 0.05                | 0.07               | <0.01               | 0.05   | <0.01  |
| Biochemical Oxygen Demand                                     | mg/L      | 2                                   | 1 <sup>E</sup>  | 2   | NE <sup>D</sup>   | -                  | 8                   | 9                              | 4                              | 5                  | 3                   | 201                | <2                  | 7  | <2   |
| Enterococci   | CFU/100mL | 1                                   | 10  | NE <sup>D</sup>                             | 230 <sup>C</sup>  | -                  | 180                 | ~6000                          | 26                             | 82                 | ~6                  | 1400               | ~5                  | 140  | 22   |

A= Note values are physical and chemical stressors for south-east Australia for slightly disturbed ecosystems.

B= Rainfall data examined for up to 5 days prior to the sampling event.

C= Value is recreational guideline for secondary contact, e.g. boating. Recommended value for primary contact, e.g. swimming, is 35 CFU/100mL.

D= Guideline not established.

E= Guideline is below LOR, therefore results less than LOR cannot be determined as above or below guideline.

F= Guidelines are mode values determined from data taken over a period from 1994-2010.



Table 3.2 Tudar Road Wetland Water Quality Data.

| ALS Workgroup Number   |           |                                     |  |   |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805   | EW1101805   | EW1102223   | EW1102223   |
|--|-----------|-------------------------------------|--|---|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|---|---|---|---|
| Sample Date  |           |                                     |  |   |   | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011   | 8/06/2011   | 28/07/2011  | 28/07/2011  |
| Sampling Site  |           |                                     |  |   |   | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow)  | Point 38B (Outflow)   | Point 38A (Inflow)                                      | Point 38B (Outflow)                                     |
| Rainfall Oyster Bay (Green Point Road) 2.1km away <sup>B</sup> |           |                                     |  |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 7mm 11/4/2011      | 7mm 11/4/2011       | 2mm 10/5/2011      | 2mm 10/5/2011       | 3.1mm 7/6/2011 <sup>G</sup> ,<br>3.1mm 6/6/2011 <sup>G</sup> ,<br>3.1mm 5/6/2011 <sup>G</sup> ,<br>3.1mm 4/6/2011 <sup>G</sup> ,<br>3.1mm 3/6/2011 <sup>G</sup> | 3.1mm 7/6/2011 <sup>G</sup> ,<br>3.1mm 6/6/2011 <sup>G</sup> ,<br>3.1mm 5/6/2011 <sup>G</sup> ,<br>3.1mm 4/6/2011 <sup>G</sup> ,<br>3.1mm 3/6/2011 <sup>G</sup> | 0.4mm 27/7/2011,<br>1.6mm 26/7/2011,<br>4.6mm 23/7/2011 | 0.4mm 27/7/2011,<br>1.6mm 26/7/2011,<br>4.6mm 23/7/2011 |
| Rainfall Oatley (Woronora Parade) 4.8km away <sup>B</sup>      |           |                                     |  |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 6mm 11/4/2011      | 6mm 11/4/2011       | 1.2mm 10/5/2011    | 1.2mm 10/5/2011     | 0.6mm 5/6/2011,<br>0.4mm 3/6/2011   | 0.6mm 5/6/2011,<br>0.4mm 3/6/2011   | 0.8mm 26/7/2011,<br>0.4mm 25/7/2011,<br>31mm 23/7/2011  | 0.8mm 26/7/2011,<br>0.4mm 25/7/2011,<br>31mm 23/7/2011  |
|  | Units     | Laboratory Limit of Reporting (LOR) | Georges River Catchment Control Site Woronora River <sup>F</sup> | Australian Runoff Quality Guidelines (2006) | ANZECC Protection of Aquatic Ecosystems Guidelines 95% (2000) |                    |                     |                    |                     |                    |                     |   |   |   |   |
| pH   | pH Unit   | 0.1                                 | 7.2  | NE <sup>D</sup>                             | 6.5 - 8.0 <sup>A</sup>  | 7.1                | 6.5                 | 6.8                | 6.6                 | 6.3                | 6.9                 | 7.4   | 6.9   | 7.4   | 7   |
| Electrical Conductivity (NC)                                   | µS/cm     | 1                                   | 190  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 460                | 310                 | 353                | 266                 | 503                | 427                 | 473   | 410   | 419   | 402   |
| Dissolved Oxygen   | mg/L      | 0.01                                | 11.1   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 7.1                | 3.1                 | 5.13               | 3.43                | 7.3                | 4.15                | 9.95  | 4.92  | 10.2  | 6.21  |
| Temperature  | °C        | 0.1                                 | 9.9  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 29                 | 26.1                | 20.7               | 15.3                | 15.7               | 12.5                | 14.4  | 10.8  | 14.6  | 12.2  |
| Suspended Solids (SS)  | mg/L      | 1                                   | 2  | 25  | NE <sup>D</sup>   | 1                  | 5                   | 6                  | <1                  | 290                | <1                  | <1  | <1  | 2   | 1   |
| Arsenic  | mg/L      | 0.001                               | 0.001  | NE <sup>D</sup>                             | 0.024   | <0.001             | <0.001              | <0.001             | <0.001              | 0.002              | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Cadmium  | mg/L      | 0.0001                              | NE <sup>D</sup>  | 0.0004                                      | 0.0002  | <0.0001            | <0.0001             | <0.0001            | <0.0001             | 0.0004             | <0.0001             | <0.0001   | <0.0001   | <0.0001   | <0.0001   |
| Chromium   | mg/L      | 0.001                               | NE <sup>D</sup>  | 0.01  | NE <sup>D</sup>   | <0.001             | <0.001              | <0.001             | <0.001              | 0.004              | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Copper   | mg/L      | 0.001                               | 0.05   | 0.01  | 0.0014  | <0.001             | <0.001              | 0.001              | <0.001              | 0.029              | <0.001              | 0.002   | <0.001  | 0.002   | 0.002   |
| Nickel   | mg/L      | 0.001                               | NE <sup>D</sup>  | NE <sup>D</sup>                             | 0.011   | <0.001             | <0.001              | <0.001             | <0.001              | 0.004              | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Lead   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>  | 0.025                                       | 0.0034  | <0.001             | <0.001              | 0.001              | <0.001              | 0.044              | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Zinc   | mg/L      | 0.005                               | 0.005  | 0.05  | 0.008   | 0.088              | <0.005              | 0.512              | 0.007               | 2.31               | 0.006               | 0.068   | 0.015   | 0.036   | 0.037   |
| Ammonia as N   | mg/L      | 0.01                                | 0.005 <sup>E</sup>   | NE <sup>D</sup>                             | 0.9   | 0.11               | 0.02                | <0.01              | <0.01               | 0.91               | 0.03                | 0.05  | 0.02  | 0.02  | 0.02  |
| Nitrite + Nitrate as N   | mg/L      | 0.01                                | NE <sup>D</sup>  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.03               | 0.01                | 0.25               | 0.03                | 0.86               | 0.02                | 0.96  | 0.03  | 0.75  | 0.22  |
| Total Kjeldahl Nitrogen as N                                   | mg/L      | 0.1                                 | 0.005 <sup>E</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.5                | 0.5                 | 0.9                | 0.3                 | –                  | –                   | 0.5   | <0.1  | <0.1  | <0.1  |
| Total Nitrogen as N  | mg/L      | 0.1                                 | 0.005 <sup>E</sup>   | 0.5   | 0.5 <sup>A</sup>  | 0.5                | 0.5                 | 1.2                | 0.3                 | 11.2               | 0.3                 | 1.5   | <0.1  | 0.8   | 0.2   |
| Total Phosphorus as P  | mg/L      | 0.01                                | 0.05   | 0.05  | 0.05 <sup>A</sup>   | 0.22               | 0.22                | 0.07               | 0.03                | 1.94               | 0.08                | <0.01   | <0.01   | 0.02  | 0.02  |
| Biochemical Oxygen Demand                                      | mg/L      | 2                                   | 1 <sup>E</sup>   | 2   | NE <sup>D</sup>   | 4                  | 5                   | 4                  | <2                  | 55                 | 3                   | <2  | <2  | <2  | <2  |
| Enterococci  | CFU/100mL | 1                                   | 10   | NE <sup>D</sup>                             | 230 <sup>C</sup>  | 72                 | 180                 | 270                | 34                  | 4500               | ~10                 | 410   | ~6  | 200   | ~16   |

A= Note values are physical and chemical stressors for south-east Australia for slightly disturbed ecosystems.

B= Rainfall data examined for up to 5 days prior to the sampling event.

C= Value is recreational guideline for secondary contact, e.g. boating. Recommended value for primary contact, e.g. swimming, is 35 CFU/100mL.

D= Guideline not established.

E= Guideline is below LOR, therefore results less than LOR cannot be determined as above or below guideline.

F= Guidelines are mode values determined from data taken over a period from 1994-2010.

G= Note value was derived from 50.2mm on 16/6/2011, this being the total for the previous 16 days of rain from 1/6/2011 to 16/6/2011.

Table 3.3 Still Creek Detention Basin Water Quality Data.

| ALS Workgroup Number   |           |                                     |  |   |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805   | EW1101805   | EW1102223   | EW1102223   |
|--|-----------|-------------------------------------|--|---|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|---|---|---|---|
| Sample Date  |           |                                     |  |   |   | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011   | 8/06/2011   | 28/07/2011  | 28/07/2011  |
| Sampling Site  |           |                                     |  |   |   | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow)  | Point 25B (Outflow)   | Point 25A (Inflow)                                      | Point 25B (Outflow)                                     |
| Rainfall Lucas Heights (ANSTO) 5.1km away <sup>B</sup>         |           |                                     |  |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 6.8mm 11/4/2011    | 6.8mm 11/4/2011     | 0mm 5 days prior   | 0mm 5 days prior    | 0.6mm 3/6/2011  | 0.6mm 3/6/2011  | 1.4mm 27/7/2011,<br>1mm 26/7/2011,<br>36mm 23/7/2011    | 1.4mm 27/7/2011,<br>1mm 26/7/2011,<br>36mm 23/7/2011    |
| Rainfall Oyster Bay (Green Point Road) 5.4km away <sup>B</sup> |           |                                     |  |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 7mm 11/4/2011      | 7mm 11/4/2011       | 2mm 10/5/2011      | 2mm 10/5/2011       | 3.1mm 7/6/2011 <sup>C</sup> ,<br>3.1mm 6/6/2011 <sup>C</sup> ,<br>3.1mm 5/6/2011 <sup>C</sup> ,<br>3.1mm 4/6/2011 <sup>C</sup> ,<br>3.1mm 3/6/2011 <sup>C</sup> | 3.1mm 7/6/2011 <sup>C</sup> ,<br>3.1mm 6/6/2011 <sup>C</sup> ,<br>3.1mm 5/6/2011 <sup>C</sup> ,<br>3.1mm 4/6/2011 <sup>C</sup> ,<br>3.1mm 3/6/2011 <sup>C</sup> | 0.4mm 27/7/2011,<br>1.6mm 26/7/2011,<br>4.6mm 23/7/2011 | 0.4mm 27/7/2011,<br>1.6mm 26/7/2011,<br>4.6mm 23/7/2011 |
|  | Units     | Laboratory Limit of Reporting (LOR) | Georges River Catchment Control Site Woronora River <sup>F</sup> | Australian Runoff Quality Guidelines (2006) | ANZECC Protection of Aquatic Ecosystems Guidelines 95% (2000) |                    |                     |                    |                     |                    |                     |   |   |   |   |
| pH   | pH Unit   | 0.1                                 | 7.2  | NE <sup>D</sup>                             | 6.5 - 8.0 <sup>A</sup>  | 7.7                | 7.1                 | 7.4                | 7                   | 6.7                | 6.7                 | 7.8   | 7.4   | 7.8   | 7.4   |
| Electrical Conductivity (NC)                                   | µS/cm     | 1                                   | 190  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 500                | 400                 | 388                | 148                 | 346                | 420                 | 496   | 522   | 822   | 653   |
| Dissolved Oxygen   | mg/L      | 0.01                                | 11.1   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 9.66               | 8.27                | 9.2                | 4.95                | 10.9               | 7.4                 | 11.3  | 6.36  | 9.91  | 7.58  |
| Temperature  | °C        | 0.1                                 | 9.9  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 28.7               | 30.1                | 18                 | 17.7                | 12.9               | 12.4                | 11.4  | 9   | 11.5  | 11.9  |
| Suspended Solids (SS)  | mg/L      | 1                                   | 2  | 25  | NE <sup>D</sup>   | 32                 | 20                  | 2                  | 3                   | 3                  | 3                   | <1  | 10  | 2   | 3   |
| Arsenic  | mg/L      | 0.001                               | 0.001  | NE <sup>D</sup>                             | 0.024   | <0.001             | <0.001              | <0.001             | <0.001              | <0.001             | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Cadmium  | mg/L      | 0.0001                              | NE <sup>D</sup>  | 0.0004                                      | 0.0002  | 0.0005             | 0.0003              | <0.0001            | 0.0001              | <0.0001            | <0.0001             | <0.0001   | <0.0001   | <0.0001   | <0.0001   |
| Chromium   | mg/L      | 0.001                               | NE <sup>D</sup>  | 0.01  | NE <sup>D</sup>   | 0.001              | <0.001              | <0.001             | <0.001              | <0.001             | <0.001              | <0.001  | <0.001  | 0.018   | <0.001  |
| Copper   | mg/L      | 0.001                               | 0.05   | 0.01  | 0.0014  | <0.001             | <0.001              | 0.002              | 0.002               | 0.001              | <0.001              | 0.001   | 0.001   | 0.004   | 0.003   |
| Nickel   | mg/L      | 0.001                               | NE <sup>D</sup>  | NE <sup>D</sup>                             | 0.011   | <0.001             | <0.001              | <0.001             | <0.001              | <0.001             | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Lead   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>  | 0.025                                       | 0.0034  | <0.001             | <0.001              | <0.001             | <0.001              | <0.001             | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Zinc   | mg/L      | 0.005                               | 0.005  | 0.05  | 0.008   | 0.008              | 0.006               | 0.028              | 0.011               | 0.015              | 0.01                | 0.016   | 0.017   | 0.029   | 0.025   |
| Ammonia as N   | mg/L      | 0.01                                | 0.005 <sup>E</sup>   | NE <sup>D</sup>                             | 0.9   | 0.06               | 0.04                | <0.01              | 0.03                | 0.03               | 0.04                | 0.04  | 0.05  | 0.03  | 0.1   |
| Nitrite + Nitrate as N   | mg/L      | 0.01                                | NE <sup>D</sup>  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.02               | 0.02                | 0.13               | 0.04                | 0.33               | 0.11                | 0.63  | 0.13  | 2.05  | 0.98  |
| Total Kjeldahl Nitrogen as N                                   | mg/L      | 0.1                                 | 0.005 <sup>E</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.7                | 0.5                 | 0.4                | 0.4                 | –                  | –                   | 0.3   | 0.4   | <0.1  | 0.4   |
| Total Nitrogen as N  | mg/L      | 0.1                                 | 0.005 <sup>E</sup>   | 0.5   | 0.5 <sup>A</sup>  | 0.7                | 0.5                 | 0.5                | 0.4                 | 0.6                | 0.5                 | 0.9   | 0.5   | 2   | 1.4   |
| Total Phosphorus as P  | mg/L      | 0.01                                | 0.05   | 0.05  | 0.05 <sup>A</sup>   | 0.16               | 0.05                | 0.02               | 0.12                | 0.02               | 0.06                | 0.21  | 0.13  | <0.01   | 0.01  |
| Biochemical Oxygen Demand                                      | mg/L      | 2                                   | 1 <sup>E</sup>   | 2   | NE <sup>D</sup>   | 8                  | 14                  | 3                  | 4                   | 3                  | 3                   | <2  | 3   | <2  | <2  |
| Enterococci  | CFU/100mL | 1                                   | 10   | NE <sup>D</sup>                             | 230 <sup>C</sup>  | 80                 | 630                 | 190                | 590                 | 38                 | 100                 | 38  | 120   | 280   | 620   |

A= Note values are physical and chemical stressors for south-east Australia for slightly disturbed ecosystems.

B= Rainfall data examined for up to 5 days prior to the sampling event.

C= Value is recreational guideline for secondary contact, e.g. boating. Recommended value for primary contact, e.g. swimming, is 35 CFU/100mL.

D= Guideline not established.

E= Guideline is below LOR, therefore results less than LOR cannot be determined as above or below guideline.

F= Guidelines are mode values determined from data taken over a period from 1994-2010.

G= Note value was derived from 50.2mm on 16/6/2011, this being the total for the previous 16 days of rain from 1/6/2011 to 16/6/2011.



Table 3.4 Burnum Burnum Detention Basin Water Quality Data.

| ALS Workgroup Number   |           |                                     |  |   |   | EW1100422          | EW1100422           | ES1107703                      | ES1107703                      | ES1109140          | ES1109140           | EW1101805   | EW1101805   | EW1102223   | EW1102223   |
|--|-----------|-------------------------------------|--|---|---|--------------------|---------------------|--------------------------------|--------------------------------|--------------------|---------------------|---|---|---|---|
| Sample Date  |           |                                     |  |   |   | 3/02/2011          | 3/02/2011           | 13/04/2011                     | 13/04/2011                     | 11/05/2011         | 11/05/2011          | 8/06/2011   | 8/06/2011   | 28/07/2011  | 28/07/2011  |
| Sampling Site  |           |                                     |  |   |   | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow)             | Point 42B (Outflow)            | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow)  | Point 42B (Outflow)   | Point 42A (Inflow)                                      | Point 42B (Outflow)                                     |
| Rainfall Audley (Royal National Park) 3.8km away <sup>B</sup>  |           |                                     |  |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 6mm 11/4/2011,<br>1mm 8/4/2011 | 6mm 11/4/2011,<br>1mm 8/4/2011 | 2mm 10/5/2011      | 2mm 10/5/2011       | 2mm 3/6/2011  | 2mm 3/6/2011  | 4mm 27/7/2011,<br>1mm 26/7/2011,<br>41mm 23/7/2011      | 4mm 27/7/2011,<br>1mm 26/7/2011,<br>41mm 23/7/2011      |
| Rainfall Oyster Bay (Green Point Road) 3.9km away <sup>B</sup> |           |                                     |  |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 7mm 11/4/2011                  | 7mm 11/4/2011                  | 2mm 10/5/2011      | 2mm 10/5/2011       | 3.1mm 7/6/2011 <sup>G</sup> ,<br>3.1mm 6/6/2011 <sup>G</sup> ,<br>3.1mm 5/6/2011 <sup>G</sup> ,<br>3.1mm 4/6/2011 <sup>G</sup> ,<br>3.1mm 3/6/2011 <sup>G</sup> | 3.1mm 7/6/2011 <sup>G</sup> ,<br>3.1mm 6/6/2011 <sup>G</sup> ,<br>3.1mm 5/6/2011 <sup>G</sup> ,<br>3.1mm 4/6/2011 <sup>G</sup> ,<br>3.1mm 3/6/2011 <sup>G</sup> | 0.4mm 27/7/2011,<br>1.6mm 26/7/2011,<br>4.6mm 23/7/2011 | 0.4mm 27/7/2011,<br>1.6mm 26/7/2011,<br>4.6mm 23/7/2011 |
|  | Units     | Laboratory Limit of Reporting (LOR) | Georges River Catchment Control Site Woronora River <sup>F</sup> | Australian Runoff Quality Guidelines (2006) | ANZECC Protection of Aquatic Ecosystems Guidelines 95% (2000) |                    |                     |                                |                                |                    |                     |   |   |   |   |
| pH   | pH Unit   | 0.1                                 | 7.2  | NE <sup>D</sup>                             | 6.5 - 8.0 <sup>A</sup>  | 7.1                | 7.9                 | 7.1                            | 7.2                            | 7.8                | 8.2                 | 7.9   | 7.6   | 8   | 7.3   |
| Electrical Conductivity (NC)                                   | µS/cm     | 1                                   | 190  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 530                | 26300               | 556                            | 6850                           | 683                | 573                 | 768   | 4150  | 709   | 2060  |
| Dissolved Oxygen   | mg/L      | 0.01                                | 11.1   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 2.11               | 8.81                | 3.7                            | 6.23                           | 6.97               | 9.03                | 8.38  | 9.72  | 8.53  | 8.84  |
| Temperature  | °C        | 0.1                                 | 9.9  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 24.7               | 30.1                | 25                             | 25                             | 14.6               | 11.6                | 13.2  | 10.7  | 13.4  | 11.4  |
| Suspended Solids (SS)  | mg/L      | 1                                   | 2  | 25  | NE <sup>D</sup>   | 5                  | 24                  | 67                             | 8                              | <1                 | 48                  | <1  | 4   | 2   | 9   |
| Arsenic  | mg/L      | 0.001                               | 0.001  | NE <sup>D</sup>                             | 0.024   | <0.001             | 0.008               | 0.002                          | <0.001                         | <0.001             | 0.001               | 0.002   | <0.001  | <0.001  | <0.001  |
| Cadmium  | mg/L      | 0.0001                              | NE <sup>D</sup>  | 0.0004                                      | 0.0002  | 0.0001             | 0.0001              | 0.0016                         | <0.0001                        | <0.0001            | <0.0001             | <0.0001   | <0.0001   | <0.0001   | <0.0001   |
| Chromium   | mg/L      | 0.001                               | NE <sup>D</sup>  | 0.01  | NE <sup>D</sup>   | <0.001             | 0.001               | 0.003                          | <0.001                         | <0.001             | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Copper   | mg/L      | 0.001                               | 0.05   | 0.01  | 0.0014  | 0.002              | 0.005               | 0.033                          | 0.002                          | 0.005              | 0.002               | 0.006   | 0.003   | 0.007   | 0.003   |
| Nickel   | mg/L      | 0.001                               | NE <sup>D</sup>  | NE <sup>D</sup>                             | 0.011   | <0.001             | 0.003               | 0.002                          | 0.001                          | <0.001             | 0.001               | 0.001   | 0.001   | <0.001  | <0.001  |
| Lead   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>  | 0.025                                       | 0.0034  | <0.001             | <0.001              | 0.018                          | <0.001                         | <0.001             | <0.001              | <0.001  | <0.001  | <0.001  | <0.001  |
| Zinc   | mg/L      | 0.005                               | 0.005  | 0.05  | 0.008   | 0.017              | 0.011               | 0.329                          | <0.005                         | 0.016              | 0.006               | 0.018   | 0.012   | 0.023   | 0.01  |
| Ammonia as N   | mg/L      | 0.01                                | 0.005 <sup>E</sup>   | NE <sup>D</sup>                             | 0.9   | 0.3                | <0.10               | 1                              | 0.03                           | 0.05               | 0.1                 | 0.04  | 0.14  | 0.06  | 0.15  |
| Nitrite + Nitrate as N   | mg/L      | 0.01                                | NE <sup>D</sup>  | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.07               | 0.03                | 0.19                           | 0.04                           | 0.51               | 0.03                | 0.43  | 0.1   | 0.28  | 0.18  |
| Total Kjeldahl Nitrogen as N                                   | mg/L      | 0.1                                 | 0.005 <sup>E</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 1                  | 1.3                 | 2.2                            | 1.1                            | –                  | –                   | 0.4   | 0.5   | <0.1  | 1   |
| Total Nitrogen as N  | mg/L      | 0.1                                 | 0.005 <sup>E</sup>   | 0.5   | 0.5 <sup>A</sup>  | 1.1                | 1.3                 | 2.4                            | 1.1                            | 1                  | 0.8                 | 0.8   | 0.6   | 0.3   | 1.2   |
| Total Phosphorus as P  | mg/L      | 0.01                                | 0.05   | 0.05  | 0.05 <sup>A</sup>   | 0.4                | 0.16                | 0.08                           | 0.02                           | 0.14               | 0.21                | <0.01   | <0.01   | <0.01   | 0.04  |
| Biochemical Oxygen Demand                                      | mg/L      | 2                                   | 1 <sup>E</sup>   | 2   | NE <sup>D</sup>   | 5                  | 8                   | 12                             | 5                              | <2                 | 4                   | <2  | <2  | <2  | <2  |
| Enterococci  | CFU/100mL | 1                                   | 10   | NE <sup>D</sup>                             | 230 <sup>C</sup>  | 62                 | 56                  | 8600                           | 24                             | ~16                | ~10                 | 20  | 20  | 62  | 36  |

A= Note values are physical and chemical stressors for south-east Australia for slightly disturbed ecosystems.

B= Rainfall data examined for up to 5 days prior to the sampling event.

C= Value is recreational guideline for secondary contact, e.g. boating. Recommended value for primary contact, e.g. swimming, is 35 CFU/100mL.

D= Guideline not established.

E= Guideline is below LOR, therefore results less than LOR cannot be determined as above or below guideline.

F= Guidelines are mode values determined from data taken over a period from 1994-2010.

G= Note value was derived from 50.2mm on 16/6/2011, this being the total for the previous 16 days of rain from 1/6/2011 to 16/6/2011.

Table 3.5 Gunnamatta Bay GPT Water Quality Data.

| ALS Workgroup Number   |           |                                     |   |   |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223   | EW1102223   |
|--|-----------|-------------------------------------|---|---|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|---|---|
| Sample Date  |           |                                     |   |   |   | 03/02/2011         | 03/02/2011          | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 08/06/2011         | 08/06/2011          | 28/07/2011  | 28/07/2011  |
| Sampling Site  |           |                                     |   |   |   | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow)  | Point 11B (Outflow)   |
| Rainfall Cronulla South Bowling Club 2.2km away <sup>B</sup> |           |                                     |   |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 7mm 11/4/2011      | 7mm 11/4/2011       | 10.8mm 10/5/2011   | 10.8mm 10/5/2011    | 0mm 5 days prior   | 0mm 5 days prior    | 1mm 27/7/2011, 1mm 26/7/2011, 1.4mm 25/7/2011, 35mm 23/7/2011 | 1mm 27/7/2011, 1mm 26/7/2011, 1.4mm 25/7/2011, 35mm 23/7/2011 |
| Rainfall Sans Souci (Public School) 6.5km away <sup>B</sup>  |           |                                     |   |   |   | 0mm 5 days prior   | 0mm 5 days prior    | 4mm 11/4/2011      | 4mm 11/4/2011       | 5mm 10/5/2011      | 5mm 10/5/2011       | 2mm 3/6/2011       | 2mm 3/6/2011        | 1mm 26/7/2011, 32mm 23/7/2011                                 | 1mm 26/7/2011, 32mm 23/7/2011                                 |
|  | Units     | Laboratory Limit of Reporting (LOR) | Port Hacking River Catchment Control Site Kangaroo Creek <sup>F</sup> | Australian Runoff Quality Guidelines (2006) | ANZECC Protection of Aquatic Ecosystems Guidelines 95% (2000) |                    |                     |                    |                     |                    |                     |                    |                     |   |   |
| pH   | pH Unit   | 0.1                                 | 7.5   | NE <sup>D</sup>                             | 6.5 - 8.0 <sup>A</sup>  | 7.7                | 7.8                 | 7.9                | 8.1                 | 7.2                | 7.9                 | 7.9                | 8                   | 7.9   | 7.9   |
| Electrical Conductivity (NC)                                 | µS/cm     | 1                                   | 240   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 36400              | 34200               | 344                | 1640                | 28100              | 45600               | 12400              | 34300               | 4520  | 11200   |
| Dissolved Oxygen   | mg/L      | 0.01                                | 5.8   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 8.22               | 6.75                | 6.38               | 7.25                | 9.82               | 7.35                | 10.4               | 9.79                | 9.64  | 9.32  |
| Temperature  | °C        | 0.1                                 | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 27.7               | 26.7                | 20.2               | 21                  | 14.7               | 16                  | 13.7               | 13                  | 15.6  | 16  |
| Suspended Solids (SS)  | mg/L      | 1                                   | 2   | 25  | NE <sup>D</sup>   | 2                  | 10                  | 4                  | 4                   | <1                 | 1                   | 7                  | 6                   | 37  | 14  |
| Arsenic  | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | NE <sup>D</sup>                             | 0.024   | 0.009              | 0.012               | <0.001             | <0.010              | 0.002              | <0.010              | <0.001             | <0.001              | <0.001  | <0.001  |
| Cadmium  | mg/L      | 0.0001                              | NE <sup>D</sup>   | 0.0004                                      | 0.0002  | 0.0015             | 0.0006              | 0.0012             | <0.0010             | 0.0002             | <0.0010             | <0.0001            | <0.0001             | <0.0001   | <0.0001   |
| Chromium   | mg/L      | 0.001                               | NE <sup>D</sup>   | 0.01  | NE <sup>D</sup>   | <0.005             | <0.005              | <0.001             | <0.010              | <0.001             | <0.010              | <0.001             | <0.001              | <0.001  | 0.001   |
| Copper   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | 0.01  | 0.0014  | <0.020             | <0.020              | 0.007              | <0.020              | 0.006              | <0.020              | 0.006              | 0.006               | 0.012   | 0.009   |
| Nickel   | mg/L      | 0.001                               | NE <sup>D</sup>   | NE <sup>D</sup>                             | 0.011   | 0.006              | 0.006               | 0.003              | <0.010              | 0.004              | <0.010              | 0.002              | 0.003               | 0.002   | <0.001  |
| Lead   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | 0.025                                       | 0.0034  | <0.005             | <0.005              | 0.004              | <0.010              | 0.008              | <0.010              | <0.001             | <0.001              | <0.001  | 0.002   |
| Zinc   | mg/L      | 0.005                               | 0.005   | 0.05  | 0.008   | 0.066              | <0.026              | 0.019              | <0.050              | 0.024              | <0.052              | 0.019              | 0.014               | 0.02  | 0.017   |
| Ammonia as N   | mg/L      | 0.01                                | 0.005 <sup>E</sup>  | NE <sup>D</sup>                             | 0.9   | <0.10              | <0.10               | 0.12               | <0.10               | <0.10              | <0.10               | <0.10              | <0.10               | 0.13  | 0.11  |
| Nitrite + Nitrate as N                                       | mg/L      | 0.01                                | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.1                | 0.09                | 1.38               | 0.2                 | 1.68               | 0.13                | 1.53               | 0.37                | 1.68  | 0.86  |
| Total Kjeldahl Nitrogen as N                                 | mg/L      | 0.1                                 | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 0.3                | <0.1                | 0.6                | 0.3                 | –                  | –                   | 0.4                | 0.2                 | 0.3   | 0.2   |
| Total Nitrogen as N  | mg/L      | 0.1                                 | 0.2   | 0.5   | 0.5 <sup>A</sup>  | 0.4                | <0.1                | 2                  | 0.5                 | 2.3                | 0.4                 | 1.9                | 0.6                 | 2   | 1.1   |
| Total Phosphorus as P  | mg/L      | 0.01                                | 0.005 <sup>E</sup>  | 0.05  | 0.05 <sup>A</sup>   | 0.08               | 0.12                | 0.05               | <0.01               | 0.07               | <0.01               | 0.04               | 0.01                | 0.06  | 0.06  |
| Biochemical Oxygen Demand                                    | mg/L      | 2                                   | 1 <sup>E</sup>  | 2   | NE <sup>D</sup>   | 7                  | 6                   | 4                  | 3                   | 3                  | <2                  | <2                 | 3                   | 3   | <2  |
| Enterococci  | CFU/100mL | 1                                   | 10  | NE <sup>D</sup>                             | 230 <sup>C</sup>  | 330                | 90                  | ~1600              | 640                 | 1200               | 130                 | 560                | 260                 | 1300  | 800   |

A= Note values are physical and chemical stressors for south-east Australia for slightly disturbed ecosystems.

B= Rainfall data examined for up to 5 days prior to the sampling event.

C= Value is recreational guideline for secondary contact, e.g. boating. Recommended value for primary contact, e.g. swimming, is 35 CFU/100mL.

D= Guideline not established.

E= Guideline is below LOR, therefore results less than LOR cannot be determined as above or below guideline.

F= Guidelines are mode values determined from data taken over a period from 1994-2010.



Table 3.6 Cronulla Beach GPT Water Quality Data.

| ALS Workgroup Number   |           |                                     |   |   |   | EW1100422         | EW1100422          | ES1107703         | ES1107703          | ES1109140         | ES1109140          | EW1101805         | EW1101805          | EW1102223   | EW1102223   |
|--|-----------|-------------------------------------|---|---|---|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|---|---|
| Sample Date  |           |                                     |   |   |   | 03/02/2011        | 03/02/2011         | 13/04/2011        | 13/04/2011         | 11/05/2011        | 11/05/2011         | 08/06/2011        | 08/06/2011         | 28/07/2011  | 28/07/2011  |
| Sampling Site  |           |                                     |   |   |   | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow)   | Point 9B (Outflow)  |
| Rainfall Cronulla South Bowling Club 2.2km away <sup>B</sup> |           |                                     |   |   |   | 0mm 5 days prior  | 0mm 5 days prior   | 7mm 11/4/2011     | 7mm 11/4/2011      | 10.8mm 10/5/2011  | 10.8mm 10/5/2011   | 0mm 5 days prior  | 0mm 5 days prior   | 1mm 27/7/2011,<br>1mm 26/7/2011<br>1.4mm 25/7/2011,<br>35mm 23/7/2011 | 1mm 27/7/2011,<br>1mm 26/7/2011<br>1.4mm 25/7/2011,<br>35mm 23/7/2011 |
| Rainfall Sans Souci (Public School) 6.5km away <sup>B</sup>  |           |                                     |   |   |   | 0mm 5 days prior  | 0mm 5 days prior   | 4mm 11/4/2011     | 4mm 11/4/2011      | 5mm 10/5/2011     | 5mm 10/5/2011      | 2mm 3/6/2011      | 2mm 3/6/2011       | 1mm 26/7/2011,<br>32mm 23/7/2011                                      | 1mm 26/7/2011,<br>32mm 23/7/2011                                      |
|  | Units     | Laboratory Limit of Reporting (LOR) | Port Hacking River Catchment Control Site Kangaroo Creek <sup>F</sup> | Australian Runoff Quality Guidelines (2006) | ANZECC Protection of Aquatic Ecosystems Guidelines 95% (2000) |                   |                    |                   |                    |                   |                    |                   |                    |   |   |
| pH   | pH Unit   | 0.1                                 | 7.5   | NE <sup>D</sup>                             | 6.5 - 8.0 <sup>A</sup>  | 7.6               | –                  | 7.2               | 8.5                | 8.2               | 8                  | 7.5               | 7.8                | 8.1   | 7.6   |
| Electrical Conductivity (NC)                                 | µS/cm     | 1                                   | 240   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 1330              | –                  | 776               | 15900              | 617               | 47600              | 934               | 8860               | 12200   | 1300  |
| Dissolved Oxygen   | mg/L      | 0.01                                | 5.8   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 6.18              | –                  | 5.15              | 8.56               | 8.8               | 8.43               | 9.05              | 10.9               | 10.4  | 9.23  |
| Temperature  | °C        | 0.1                                 | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 27                | –                  | 19.3              | 19.5               | 15.5              | 17                 | 15                | 14.9               | 17.3  | 17.5  |
| Suspended Solids (SS)  | mg/L      | 1                                   | 2   | 25  | NE <sup>D</sup>   | 8                 | –                  | 9                 | 7                  | 6                 | 15                 | 5                 | 5                  | 16  | 8   |
| Arsenic  | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | NE <sup>D</sup>                             | 0.024   | 0.002             | –                  | 0.001             | <0.010             | <0.001            | <0.010             | <0.001            | <0.001             | <0.001  | <0.001  |
| Cadmium  | mg/L      | 0.0001                              | NE <sup>D</sup>   | 0.0004                                      | 0.0002  | 0.0002            | –                  | <0.0001           | <0.0010            | <0.0001           | <0.0010            | <0.0001           | <0.0001            | <0.0001   | <0.0001   |
| Chromium   | mg/L      | 0.001                               | NE <sup>D</sup>   | 0.01  | NE <sup>D</sup>   | 0.001             | –                  | <0.001            | <0.010             | 0.001             | <0.010             | <0.001            | <0.001             | 0.002   | 0.003   |
| Copper   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | 0.01  | 0.0014  | 0.012             | –                  | 0.013             | <0.020             | 0.006             | <0.020             | 0.005             | 0.005              | 0.042   | 0.027   |
| Nickel   | mg/L      | 0.001                               | NE <sup>D</sup>   | NE <sup>D</sup>                             | 0.011   | 0.001             | –                  | 0.002             | <0.010             | <0.001            | <0.010             | <0.001            | <0.001             | 0.001   | <0.001  |
| Lead   | mg/L      | 0.001                               | 0.0005 <sup>E</sup>   | 0.025                                       | 0.0034  | <0.001            | –                  | 0.007             | <0.010             | <0.001            | <0.010             | <0.001            | <0.001             | 0.004   | 0.002   |
| Zinc   | mg/L      | 0.005                               | 0.005   | 0.05  | 0.008   | 0.024             | –                  | 0.042             | <0.050             | 0.011             | <0.052             | 0.02              | 0.017              | 0.073   | 0.042   |
| Ammonia as N   | mg/L      | 0.01                                | 0.005 <sup>E</sup>  | NE <sup>D</sup>                             | 0.9   | 1.29              | –                  | 0.63              | <0.10              | 0.38              | <0.10              | 0.26              | <0.10              | 0.24  | <0.10   |
| Nitrite + Nitrate as N                                       | mg/L      | 0.01                                | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 1.35              | –                  | 1.91              | 0.1                | 2.13              | 0.04               | 2.86              | 2.28               | 0.89  | 0.76  |
| Total Kjeldahl Nitrogen as N                                 | mg/L      | 0.1                                 | NE <sup>D</sup>   | NE <sup>D</sup>                             | NE <sup>D</sup>   | 3.3               | –                  | 2.7               | 1.1                | –                 | –                  | 1.8               | 0.3                | 0.6   | <0.1  |
| Total Nitrogen as N  | mg/L      | 0.1                                 | 0.2   | 0.5   | 0.5 <sup>A</sup>  | 4.6               | –                  | 4.6               | 1.2                | 4.2               | 0.1                | 4.7               | 2.6                | 1.5   | 0.8   |
| Total Phosphorus as P  | mg/L      | 0.01                                | 0.005 <sup>E</sup>  | 0.05  | 0.05 <sup>A</sup>   | 0.68              | –                  | 0.27              | 0.04               | 0.25              | <0.01              | 0.17              | 0.08               | 0.51  | 0.25  |
| Biochemical Oxygen Demand                                    | mg/L      | 2                                   | 1 <sup>F</sup>  | 2   | NE <sup>D</sup>   | 11                | –                  | 15                | 4                  | 8                 | 3                  | 4                 | 3                  | 10  | 6   |
| Enterococci  | CFU/100mL | 1                                   | 10  | NE <sup>D</sup>                             | 230 <sup>C</sup>  | 2000              | –                  | ~4000             | 710                | 2200              | 34                 | 350               | 230                | 310   | 200   |

A= Note values are physical and chemical stressors for south-east Australia for slightly disturbed ecosystems.

B= Rainfall data examined for up to 5 days prior to the sampling event.

C= Value is recreational guideline for secondary contact, e.g. boating. Recommended value for primary contact, e.g. swimming, is 35 CFU/100mL.

D= Guideline not established.

E= Guideline is below LOR, therefore results less than LOR cannot be determined as above or below guideline.

F= Guidelines are mode values determined from data taken over a period from 1994-2010.

## 3.2 Sediment Analysis

The grain size analysis demonstrated that a diversity of grain types was encountered across the six sites. Sediment was successfully collected at both the inflow and outflow of all sites with the exception of Cronulla Beach GPT, where sediment was only sampled from the inflow point. The outflow opens directly into the ocean, where the existence of tidal currents and wave action wash away any sediment that may reach that point.

### 3.2.1 Cronulla Beach GPT

The analysis of Cronulla Beach GPT inflow (Point 9A) showed that the majority of sediment at this location was sand, with a 97.98% sand content. The 1.85% of gravel could be attributed almost entirely to a single 4000 micron pebble sieved from the sample. Figure 3.111 clearly displays the primary mode which can be read from Table 3.7 as 309.46 microns. Mode 2 is also clear though distinctly smaller at 4000 microns.

### 3.2.2 Gunnamatta Bay GPT

The sediment sample from Gunnamatta Bay GPT inflow (Point 11A) was mostly sand at 73.51% with a larger gravel component at 23.50%. This gravel component consisted of a single large fragment, as with Point 9A, however smaller gravel fragments were recorded also. The impact of this single large fragment is clearly displayed in Figure 3.112 with a sharp rise in the curve at 8000 microns. The Gunnamatta Bay GPT outflow (Point 11B) did not contain a gravel component and sand formed the majority of sediment in this location at 90.31%. This is reflected in Figure 3.113 with the primary mode of 501.45 dominating the curve. Silt was also recorded in higher quantities at 8.77%, indicating an increase in finer sediment from the 2.69% measured at the inflow.

### 3.2.3 Mianga Avenue Wetland

Mianga Avenue Wetland inflow (Point 22A) was similar to Point 11A with a 70.23% sand content and 28.32% gravel component. Figure 3.114 shows however, that the sand component was shifted more towards the coarser fraction at around 600 microns. This is confirmed by looking at mode 2 in Table 3.7 which shows 690.46 microns. The gravel component from this sample contained rock fragments which produced mode 1 at 4750 microns. Interestingly, this is one of only two samples where mode 1 was produced in the gravel fraction rather than the sand component. Mianga Avenue Wetland outflow (Point 22B) yielded a greater proportion of finer sediment with the silt component dominating at 77.18%. Furthermore,



10.33% was found to be clay <4  $\mu\text{m}$  leaving the sand component relatively small at 12.49%. The site was one of only three to produce a primary mode within the mud fraction with a modal value of 22.37 microns (Fig. 3.115). It was noted however that a large quantity of organic matter was present in the sample which could have obscured the results to a certain degree. This will be addressed later, in the discussion.

### **3.2.4 Still Creek Detention Basin**

Still Creek Detention Basin inflow (Point 25A) once again demonstrated a high sand content at 84.39%. A reasonable amount of silt was also detected at 9.77% and a gravel component of 3.90%. A fair amount of organic matter was among this coarse fraction in the form of leaf fragments and bark pieces and, as with Point 22B, this will be discussed later. The high sand content was carried through to the Still Creek Detention Basin outflow (Point 25B) with 77.23% while silt rose to 15.22% and clay <4 $\mu\text{m}$  reached 7.54%. Interestingly, Figure 3.116 and Figure 3.117 are very similar with the main difference being the lack of a gravel fraction on Figure 3.117. A comparison of the primary modes reveals the subtle differences between the two sites with Point 25A at 457.50 microns and Point 25B at 602.99 microns.

### **3.2.5 Tudar Road Wetland**

The results for Tudar Road Wetland inflow (Point 38A) and Tudar Road Wetland outflow (Point 38B) were quite unusual due to sampling difficulties. Point 38A showed a high silt content at 70.75% and clay content <4 $\mu\text{m}$  of 10.37%. Sand was relatively small at 18.88%. As a result, this is the second instance where the primary mode was within the mud fraction, although in this case the result is most probably false. Tudar Road Wetland is fitted with a GPT to trap coarse sediment, litter and organic matter prior to the water entering the wetland system. Access to this device is difficult due to the depth of the collection pit and as such no sediment could be collected from within the device. The sampling was then undertaken at the next closest point, this being within the wetland itself near where the GPT discharges into it. The depth of the water in this location inhibited sampling also, but indeed any coarse sediment coming into the system is very unlikely to reach this point, as it would have already been collected by the GPT. This explains the unusual result achieved. The grain size analysis for Point 38B produced a very high gravel component of 44.88% while sand was 28.07% and silt also relatively low at 22.12%. The very high gravel measurement could be attributed to a few large pebbles which were found in the sample. These were responsible for producing the

highly skewed Figure 3.118 and Figure 3.119 and causing the primary mode to exist in the gravel fraction.

### 3.2.6 Burnum Burnum Detention Basin

Burnum Burnum Detention Basin inflow (Point 42A) produced a high sand content at 80.41% with a gravel component of 15.62%. This gravel component was characterised by the second and third modes at 2000 and 4000 microns respectively (Fig. 3.120). Although some organic matter was found in this sample the amount was small when compared with the coarse fractions of the other samples. Burnum Burnum Detention Basin outflow (Point 42B) yielded a high silt component at 72.54% and sand was greatly reduced from the inflow sample to reach 17.96%. This fine sediment content produced a primary mode of 15.57 microns making it the third site to have the primary mode within the mud fraction (Fig. 3.121). As was the case with Point 22B however, high organic matter content could be responsible for making analysis difficult and will be addressed in the discussion.

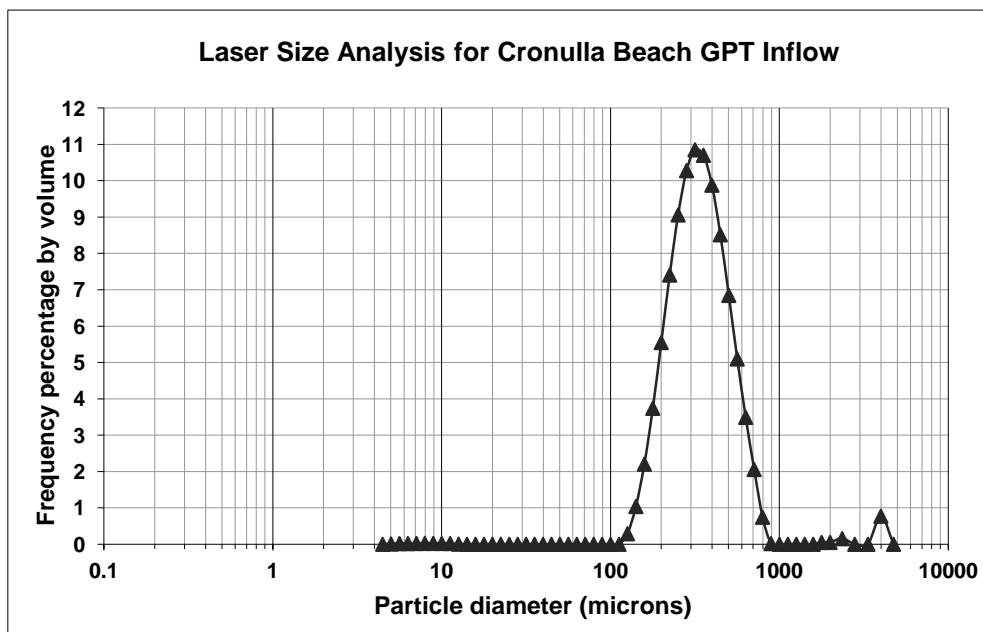


Figure 1.111 Laser Size Analysis Cronulla Beach GPT Inflow.



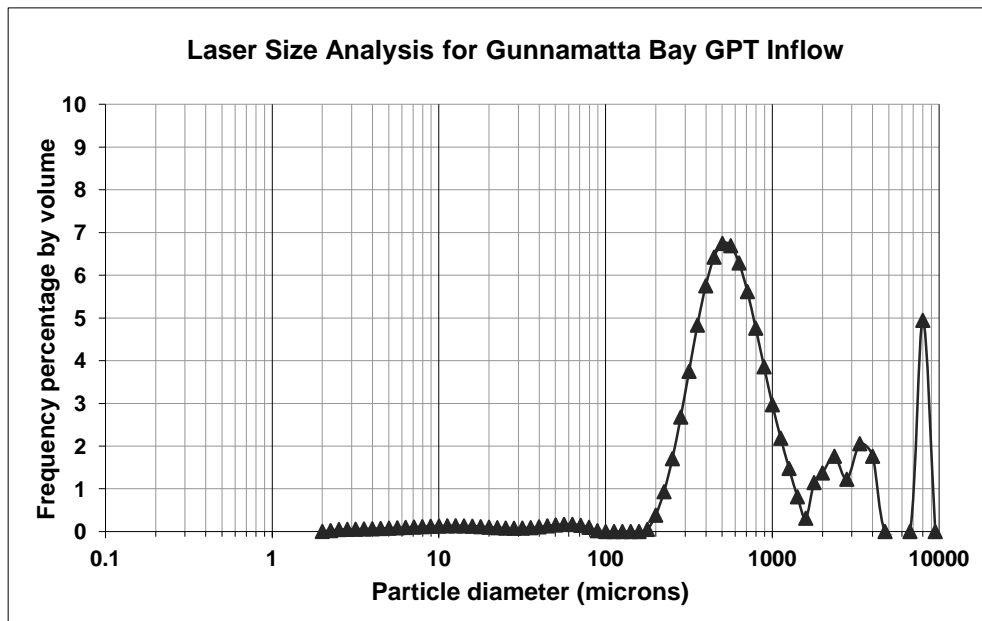


Figure 3.112 Laser Size Analysis Gunnamatta Bay GPT Inflow.

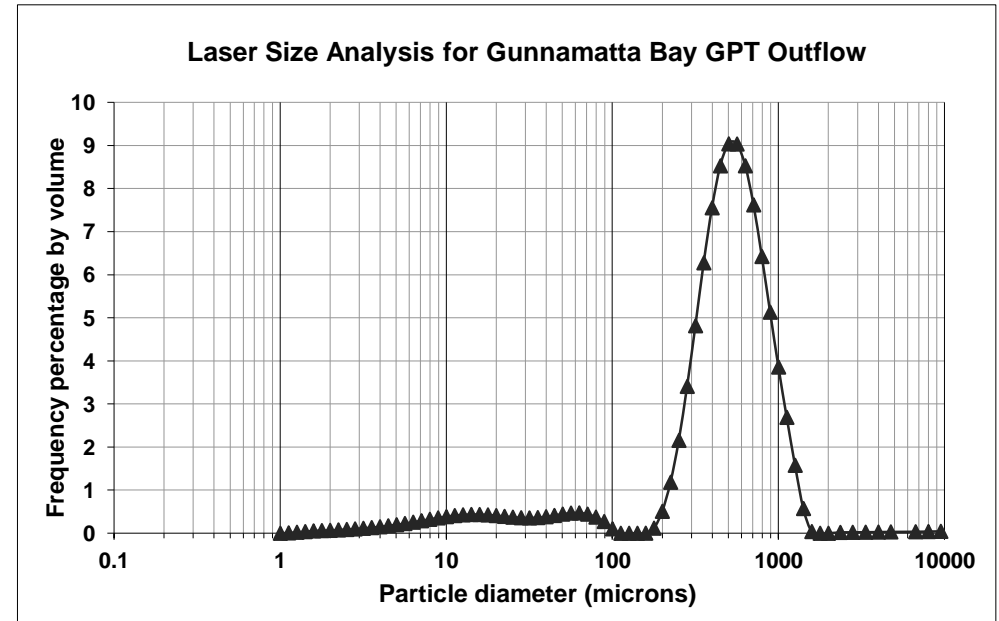


Figure 3.113 Laser Size Analysis Gunnamatta Bay GPT Outflow.

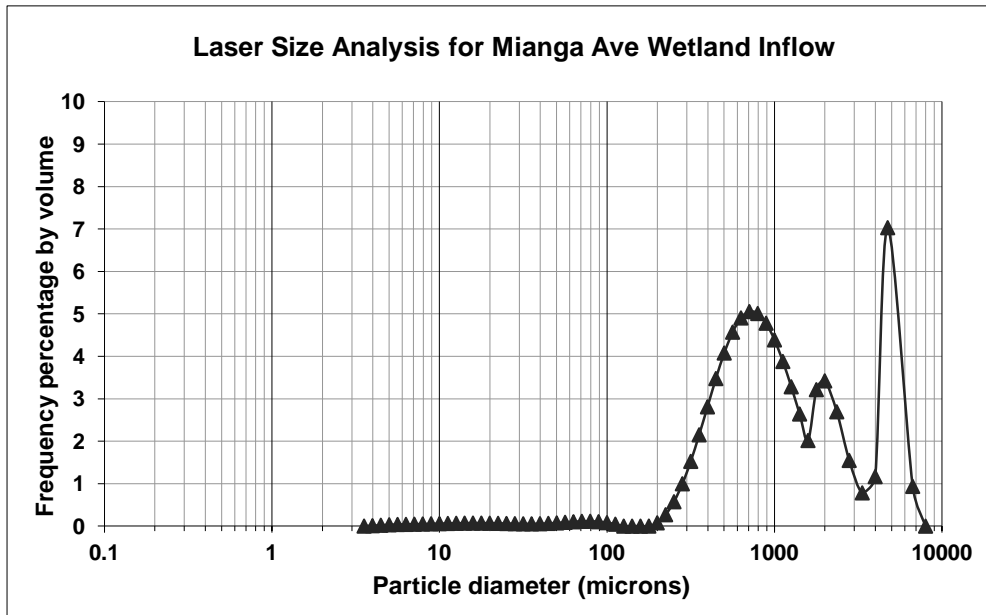


Figure 3.114 Laser Size Analysis Mianga Avenue Wetland Inflow.

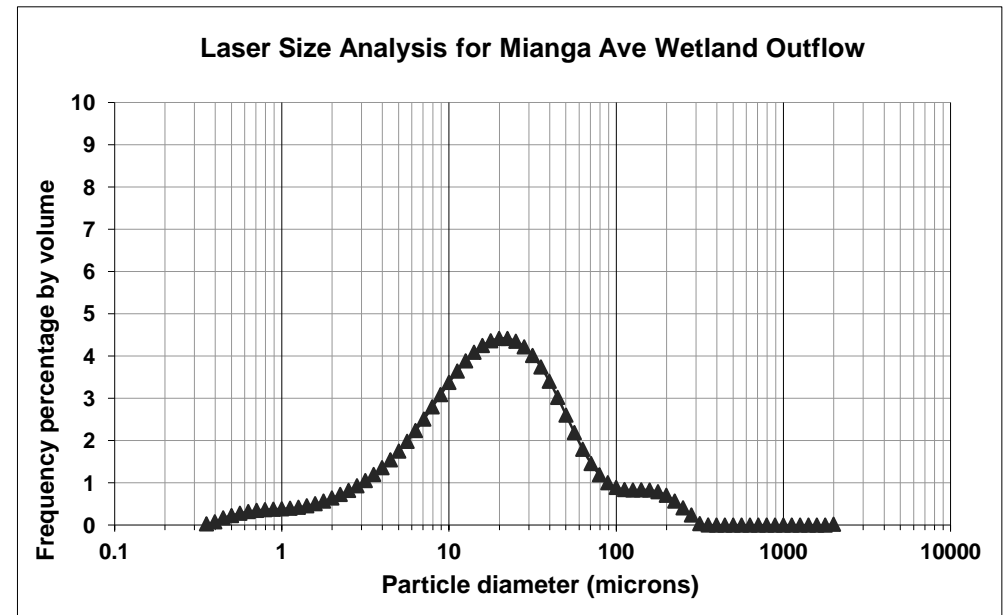


Figure 3.115 Laser Size Analysis Mianga Avenue Wetland Outflow.



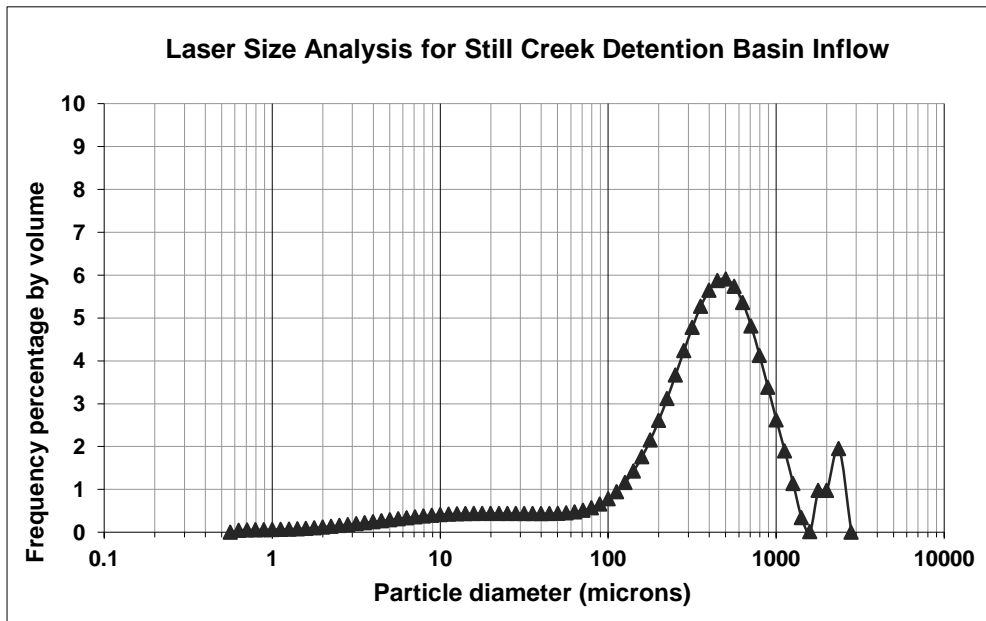


Figure 3.116 Laser Size Analysis Still Creek Detention Basin Inflow.

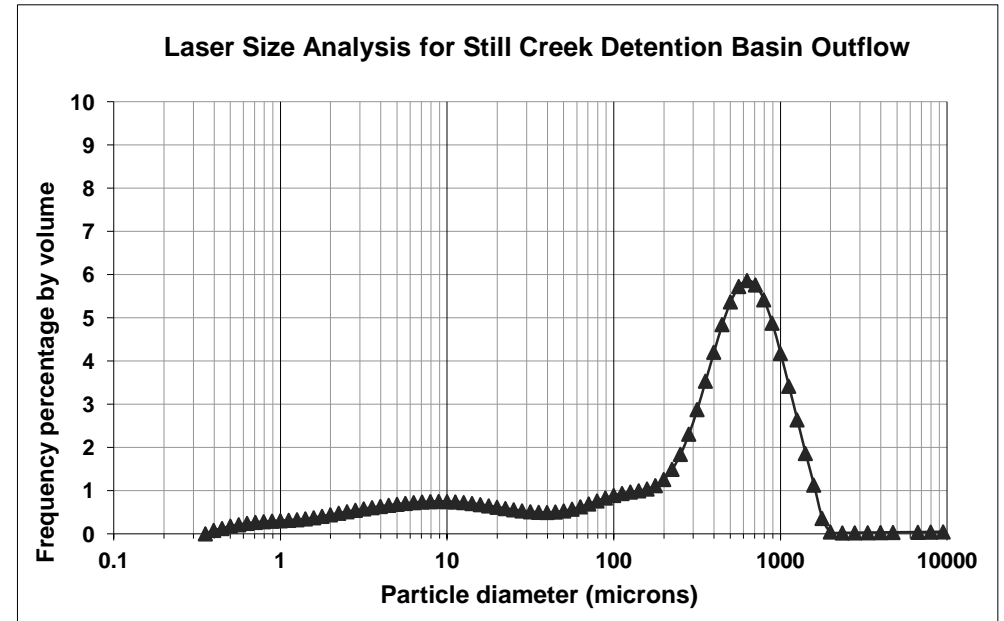


Figure 3.117 Laser Size Analysis Still Creek Detention Basin Outflow.

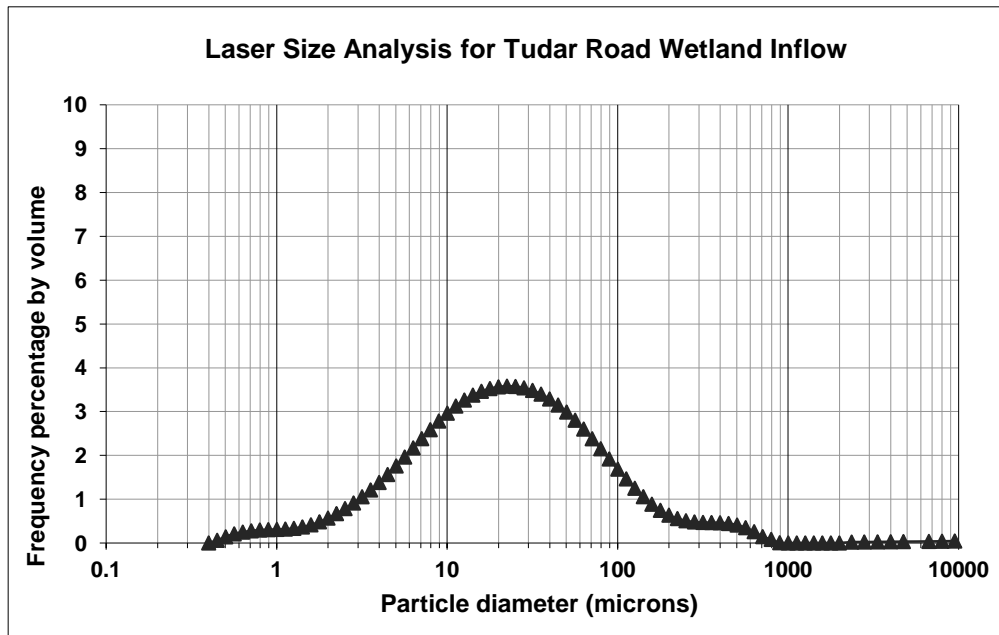


Figure 3.118 Laser Size Analysis Tudar Road Wetland Inflow.

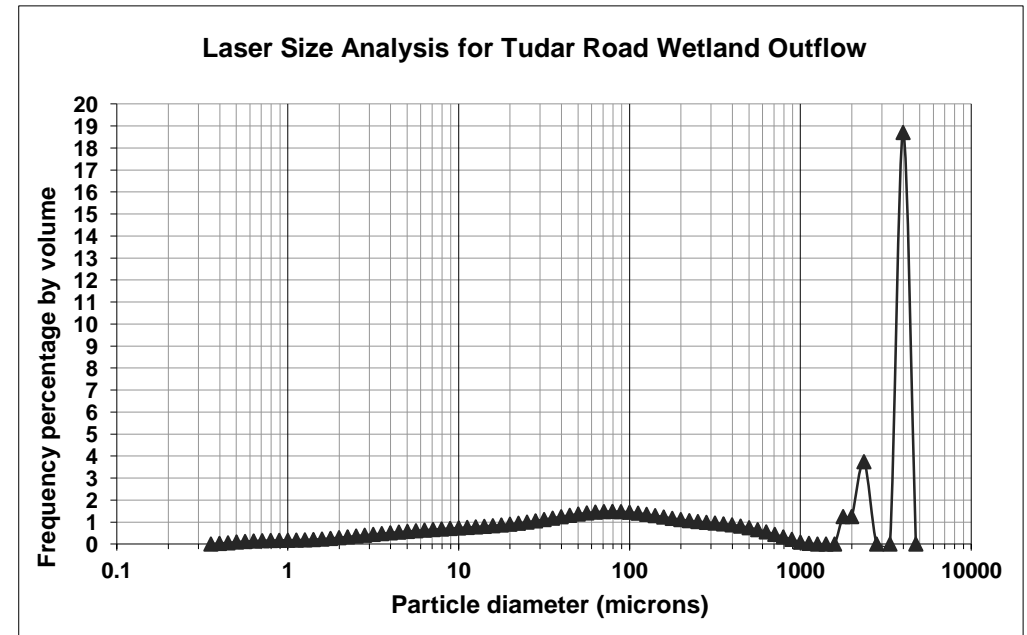


Figure 3.119 Laser Size Analysis Tudar Road Wetland Outflow.

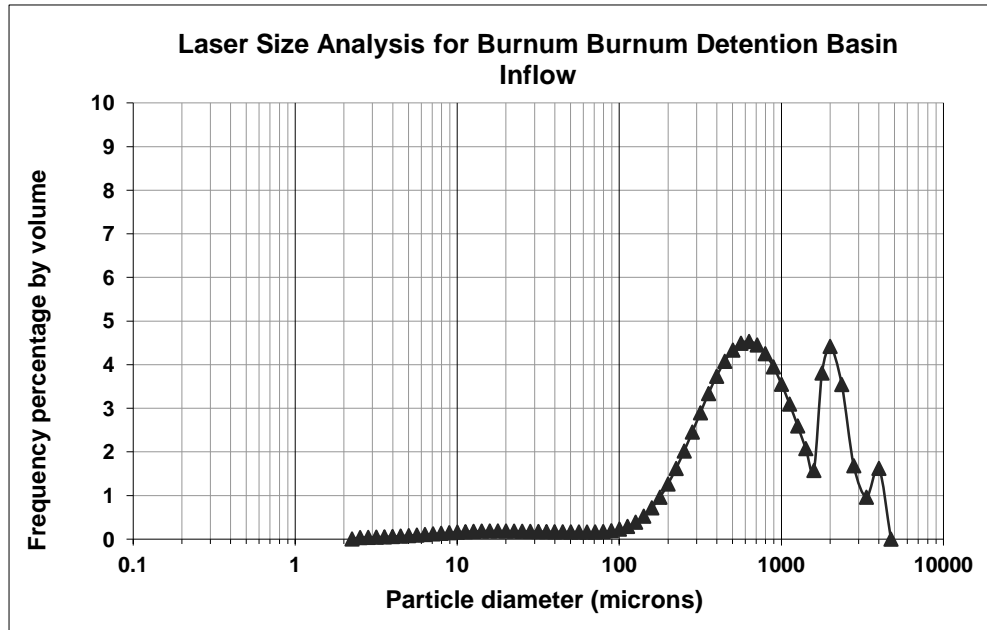


Figure 3.120 Laser Size Analysis Burnum Burnum Detention Basin Inflow.

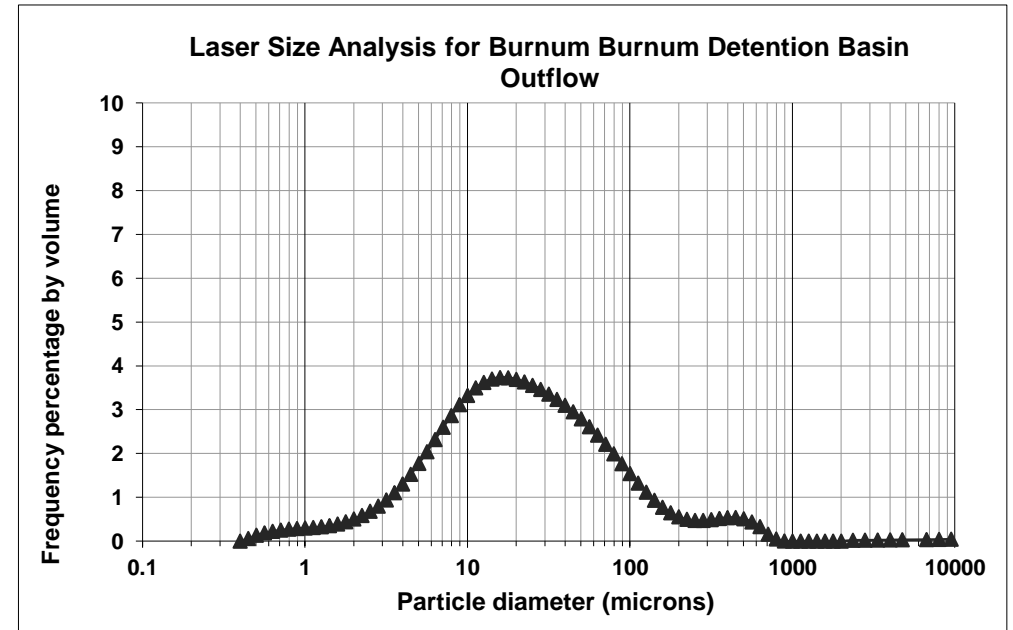


Figure 3.121 Laser Size Analysis Burnum Burnum Detention Basin Outflow.

Table 3.7 Grainsize Data.

| Sample Name         | Gravel % | Sand % | Silt % | Clay <4um % | Clay <2um % | Volume weighted mean | Mode 1 (microns) | Mode 2 (microns) | Mode 3 (microns) | Mean (microns) | Mean (phi) | Std Dev (phi) | Gskew (phi) | Kurtosis (phi) |
|---------------------|----------|--------|--------|-------------|-------------|----------------------|------------------|------------------|------------------|----------------|------------|---------------|-------------|----------------|
| Point 9A (Inflow)   | 1.85     | 97.98  | 0.16   | 0.00        | 0.00        | 397.34               | 309.46           | 4000.00          | 0.00             | 317.14         | 1.66       | 0.59          | -0.03       | 0.96           |
| Point 11A (Inflow)  | 23.50    | 73.51  | 2.69   | 0.30        | 0.00        | 1630.04              | 493.61           | 8000.00          | 3350.00          | 870.13         | 0.20       | 1.54          | -0.42       | 0.95           |
| Point 11B (Outflow) |          | 90.31  | 8.77   | 0.92        | 0.26        | 497.80               | 501.45           | 57.46            | 14.04            | 456.86         | 1.13       | 1.28          | 0.37        | 2.42           |
| Point 22A (Inflow)  | 28.32    | 70.23  | 1.44   | 0.01        | 0.00        | 1737.72              | 4750.00          | 690.46           | 2000.00          | 1282.55        | -0.36      | 1.35          | -0.13       | 0.84           |
| Point 22B (Outflow) |          | 12.49  | 77.18  | 10.33       | 4.93        | 33.86                | 22.37            | 156.61           | 0.00             | 18.32          | 5.77       | 1.70          | 0.08        | 1.19           |
| Point 25A (Inflow)  | 3.90     | 84.39  | 9.77   | 1.94        | 0.80        | 525.69               | 457.50           | 2360.00          | 0.00             | 341.25         | 1.55       | 1.81          | 0.31        | 1.82           |
| Point 25B (Outflow) |          | 77.23  | 15.22  | 7.54        | 4.18        | 452.84               | 602.99           | 8.59             | 0.00             | 175.78         | 2.51       | 2.79          | 0.65        | 1.23           |
| Point 38A (Inflow)  |          | 18.88  | 70.75  | 10.37       | 4.32        | 48.08                | 21.69            | 0.00             | 0.00             | 20.55          | 5.60       | 1.88          | 0.01        | 1.06           |
| Point 38B (Outflow) | 44.88    | 28.07  | 22.12  | 4.93        | 2.42        | 1726.56              | 4000.00          | 2360.00          | 74.33            | 420.87         | 1.25       | 3.34          | 0.50        | 0.67           |
| Point 42A (Inflow)  | 15.62    | 80.41  | 3.73   | 0.24        | 0.00        | 1110.06              | 586.18           | 2000.00          | 4000.00          | 768.32         | 0.38       | 1.40          | 0.10        | 0.92           |
| Point 42B (Outflow) |          | 17.96  | 72.54  | 9.50        | 4.05        | 48.31                | 15.57            | 403.42           | 0.00             | 20.08          | 5.64       | 1.85          | -0.05       | 1.09           |



## 4. Discussion

### 4.1 Impact of Land Use and Weather Events on Water Quality

As can be seen, a variety of responses were detected from the SQIDs in regard to the constituent concentrations of the water flowing through them. In explaining the results, it is valuable to consider the rainfall data for the days preceding the sampling event. As a result, daily rainfall data (BOM, 2011) was recorded for the five days prior to the sample date, as shown in Tables 3.1 to 3.6.

#### 4.1.1 Mianga Avenue Wetland

In examining the results for Mianga Avenue Wetland it can be seen that there was a period of high rainfall prior to the final sampling event on 28/7/2011. Paradoxically however, the concentration of suspended solids (Fig. 3.5) at the inflow was found to be low. In the study by Kayhanian et al. (2007) it was found that the average constituent event mean concentration (EMC) tends to be higher for smaller rainfall events and lower for larger events. This is due to pollutants becoming diluted by the excess water in the larger events. This relationship could be used to explain the result received at Mianga Avenue Wetland whereby the suspended sediment load could have been diluted by the larger event, namely 41 mm on 23/7/2011 (BOM, 2011), prior to sampling on the 28/7/2011. By the same theory the higher inflow reading delivered on 11/5/2011 could be explained by the small 2 mm rainfall event on 10/5/2011. Furthermore, it is possible that the time difference between the rainfall and sampling events could explain the increase in outflow concentration on 13/4/2011. Two days prior to sampling on 13/4/2011, 6 mm of rain was received, and the sediment collected by this discharge could have been transported to the outflow over that time, leaving a lower concentration at the inflow.

In applying Kayhanian et al.'s (2007) relationship to the other results for Mianga Avenue Wetland the same pattern appears to apply for TKN (Fig. 3.14), total nitrogen (Fig. 3.15) and total phosphorous (Fig. 3.16) as well as perhaps nitrite and nitrate (Fig. 3.13). Of significance also is the elevated cadmium (Fig. 3.6) level at the outflow on 13/4/2011 which corresponds with the raised suspended solids concentration. Due to the fact that most heavy metals in urban stormwater are attached to suspended solids (Herngren et al., 2005) it is quite possible that this increased cadmium originated from the suspended sediment and when digested by

the nitric acid in the sample bottle, was made available to be analysed in the water sample. The lack of any significant correlation between the metals, pH (Fig. 3.1) and electrical conductivity (Fig. 3.2) in this study resembles the results of Herngren et al. (2005) where such a response was found across the residential, industrial and commercial sites examined. Although, copper (Fig. 3.8), lead (Fig. 3.10), zinc (Fig. 3.11) and to a certain degree nickel (Fig. 3.9), did not convey a close association with the rainfall data and suspended solids in the manner discussed above, they did demonstrate a good correlation with each other, as discovered by Ki et al. (2011). In the case of that study aluminium, iron, copper and zinc formed the relationship.

As emphasised by Herngren et al. (2005) land use is a major controlling factor in the supply and impact of heavy metals on urban stormwater. It can be seen from Maps 2.7 and 2.3 that the Mianga Avenue Wetland catchment incorporates a large range of land uses with Zone 4- Local Housing and Zone 8- Urban Centre representing major portions of this. In addition to these two main uses, there are Zone 12- Special Uses areas, which include for example, educational establishments, and of particular interest, Zone 11- Employment, which incorporates an auto service centre and auto electricians. Cadmium, chromium, copper, nickel and zinc are all known to originate from car parts and engines (Wong, 2006) and it is possible that these businesses could be contributing to the concentrations of these metals detected at the SQID, particularly since they are located very close to the site. Interestingly, Figures 4.1, 4.2 and 4.3 show that the copper, zinc and lead concentrations, at the inflow, have reduced over time, though zinc has fluctuated to a much greater extent than the other two. Note, that some inflow values were excluded from these graphs due to them being extraordinarily high and limiting the graphs' ability to display other trends. Maps 2.6 and 2.2 show that there haven't been any significant changes in the catchment land uses since 2000/2001 and therefore it is reasonable to suspect that the processes involved in those land uses have changed. For example, it is possible that the reduction in vehicles relying on leaded petrol could account for a reduction in lead in the catchment (Birch and Taylor, 1999). Unfortunately, arsenic, cadmium, chromium and nickel measurements were not taken over the entire period and as a result it was difficult to make any such assertions for these metals.

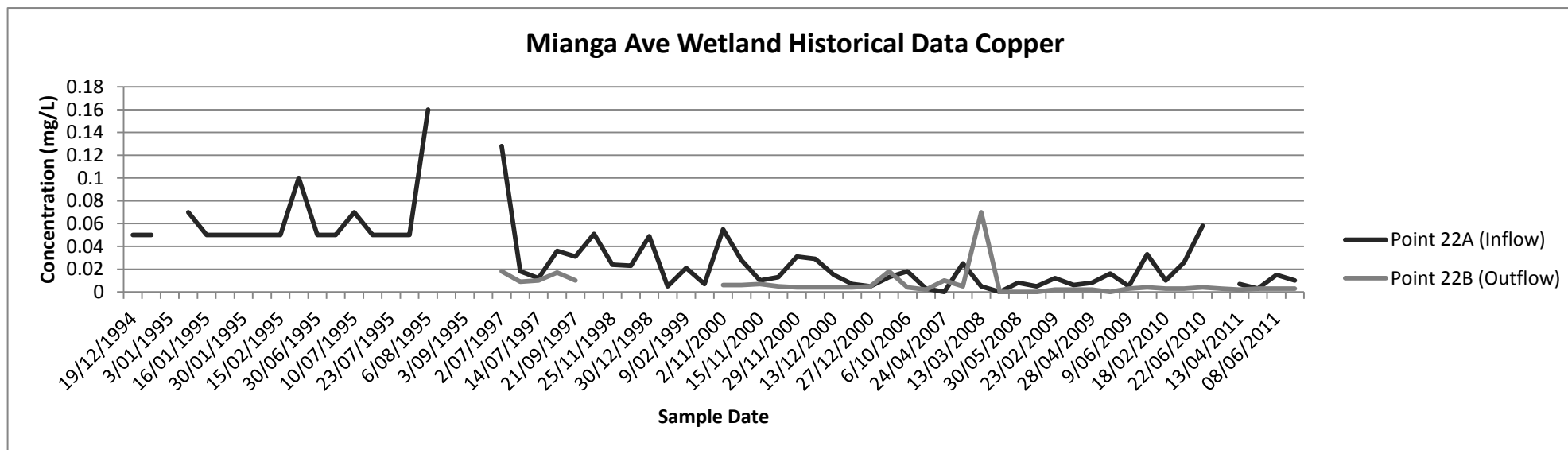


Figure 4.1 Mianga Avenue Wetland Historical Data Copper. Note excluded inflow values = 0.41mg/L on 3/1/1995, 13mg/L on 23/8/1995, 9.1mg/L on 3/9/1995, 1.9mg/L on 22/9/1995.

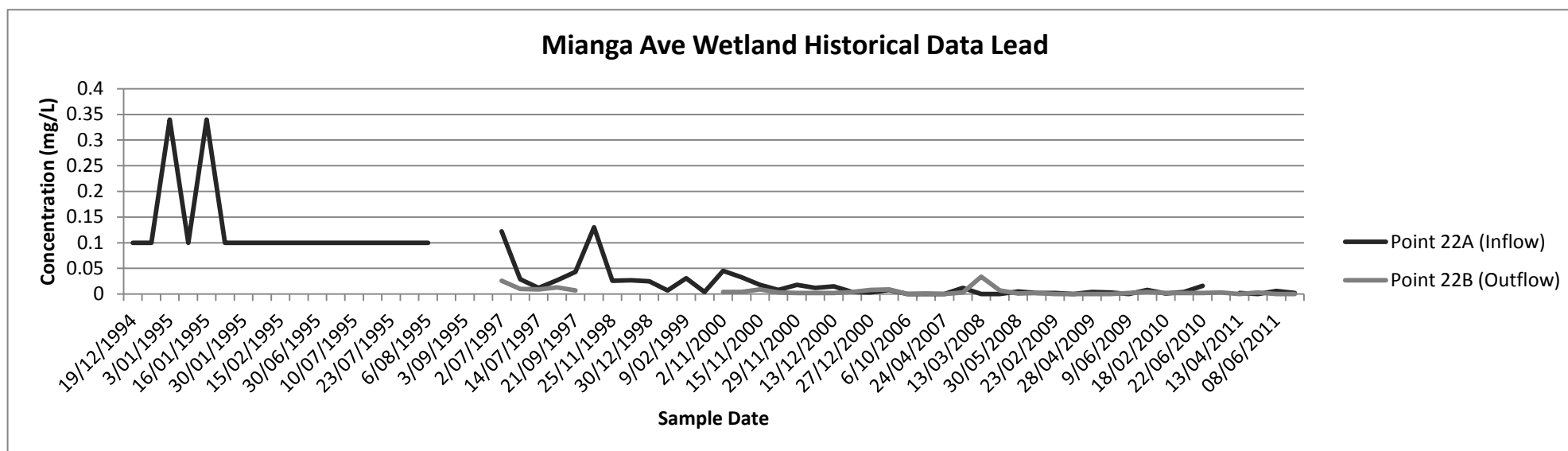


Figure 4.2 Mianga Avenue Wetland Historical Data Lead. Note excluded inflow values = 31mg/L on 23/8/1995, 0.97mg/L on 22/9/1995.



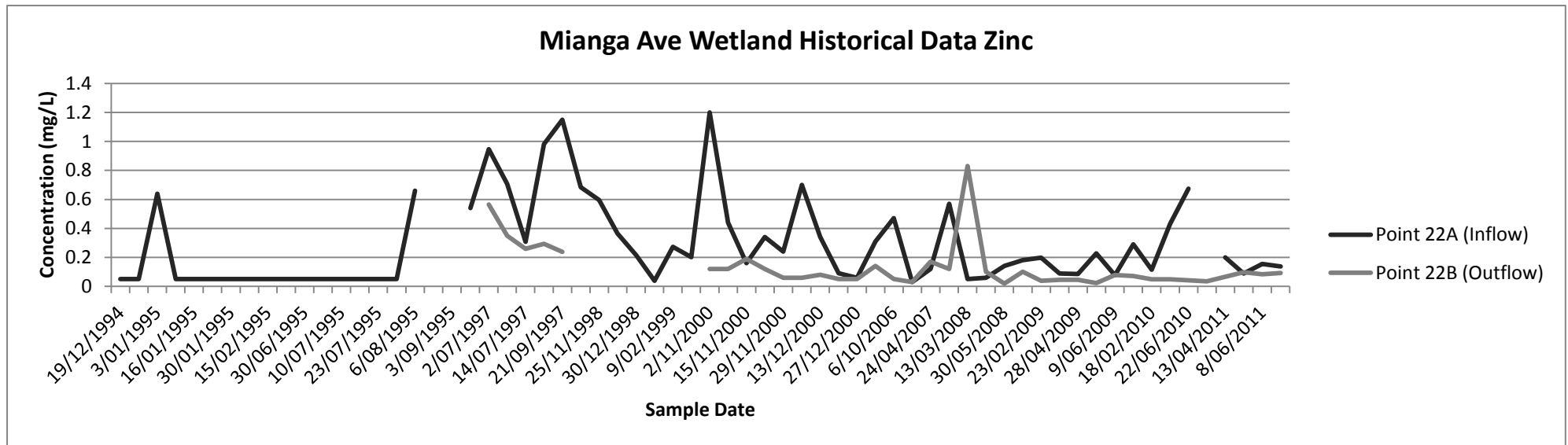


Figure 4.3 Mianga Avenue Wetland Historical Data Zinc. Note excluded inflow values = 15mg/L on 23/8/1995 and 5.9 mg/L on 3/9/1995.

#### 4.1.2 Tudar Road Wetland

In reviewing the results for Tudar Road Wetland, the major feature of interest is the pyramid shaped graphs for suspended solids (Fig. 3.23), arsenic (Fig. 3.24), cadmium (Fig. 3.25), chromium (Fig. 3.26), copper (Fig. 3.27), nickel (Fig. 3.28), lead (Fig. 3.29) and zinc (Fig. 3.30). As discussed above, the majority of heavy metals in urban stormwater are attached to suspended solids (Herngren et al., 2005) and can be liberated by the nitric acid in the sample bottle, which explains the increase in concentration of all metals examined. The increase in suspended solids can be explained by the fact that immediately prior to this sampling event, the GPT was being cleaned using a vacuum truck, therefore mobilising any sediment that had previously settled out. The other sampling events show very low sediment levels, with many below the LOR, suggesting that under normal conditions the GPT is effectively collecting and controlling sediment and therefore heavy metals. This is further supported by the historical data in Figure 4.4 which distinctly shows the elevated suspended solids on 11/5/2011. It is also possible that the land use in this location, shown on Maps 2.37 and 2.33, is less polluting in terms of heavy metals when compared with the Mianga Avenue Wetland catchment. In this area two zonings dominate, these being, Zone 3- Environmental Housing (Bushland) and Zone 4- Local Housing. As demonstrated by Maps 2.36 and 2.32, this land use has not changed since 2000/2001. It is still reasonable to consider that some heavy metal sources exist in this catchment, such as resident's vehicles, however it would receive substantially less traffic than the Mianga Avenue Wetland catchment.

The elevated concentrations of ammonia (Fig. 3.31), TKN (Fig. 3.33), total nitrogen (Fig. 3.34) and total phosphorus (Fig. 3.35) on 11/5/2011 can also be linked to the rise in suspended solids. As indicated by Haygarth and Jarvis (2002) a variety of nutrients can be transported through waterways via sediment. It can be observed that where a rise in suspended solids exists in Figure 4.4, corresponding rises can be observed in Figures 4.5 and 4.6. In fact, simply disturbing sediment by processes such as dredging can cause nutrient release (Haygarth and Jarvis, 2002). Apart from these rises, the total nitrogen and total phosphorus concentration has remained relatively constant over time. Interestingly, nitrite and nitrate (Fig. 3.32) do not display the typical pyramid graph observed, despite having the potential to be similarly affected by suspended solids.

The increase in suspended solids could also explain the increases in *Enterococci* (Fig. 3.37) and BOD (Fig. 3.36) concentrations on 11/5/2011, due to the role suspended sediment

can play in the transportation of bacteria. Xia et al. (2004) demonstrated how bacteria density was greater in water samples with suspended solids compared to those without, suggesting that suspended sediment supports the existence of bacteria. As discussed by Xia et al. (2004), nitrifying bacteria are also increased by a high suspended sediment concentration which could possibly account for the results observed for nitrite and nitrate. Figure 3.32 depicts an increase in the concentration of nitrite and nitrate on 11/5/2011, though the curve continues to rise after this on 8/6/2011, but at a much smaller rate. Perhaps the increase in nitrifying bacteria achieved on 11/5/2011 could have persisted long enough to cause the nitrification of the increased ammonia levels to form nitrite and nitrate. By the following sampling event the levels have begun to fall once more as the bacteria levels are diminished. Of interest at this site, is the apparent lack of any relationship with the rainfall experienced over the course of the sampling period.



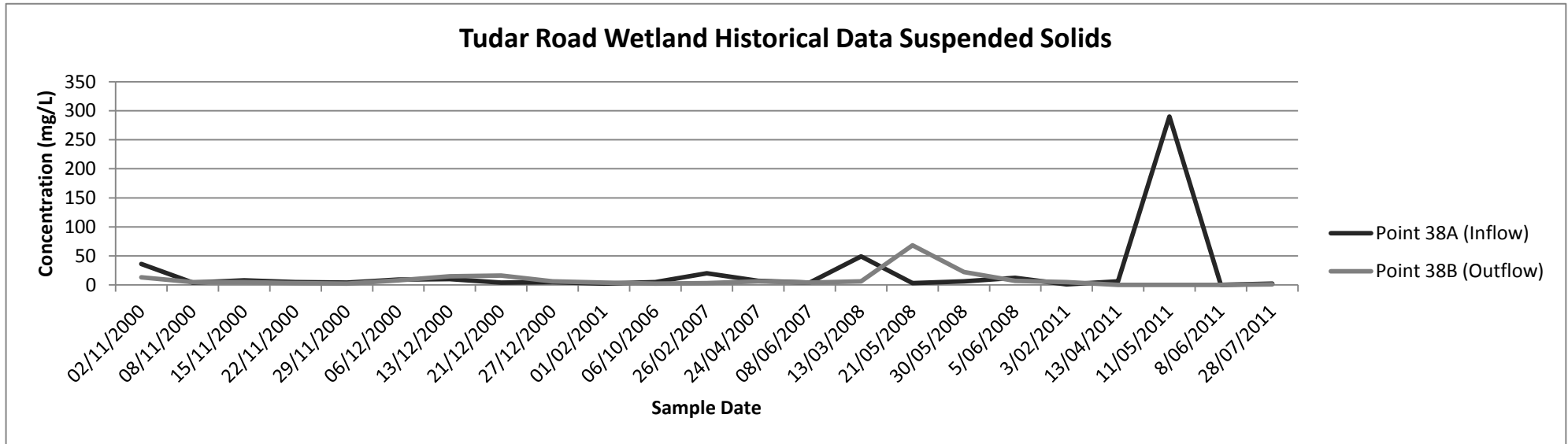


Figure 4.4 Tudor Road Wetland Historical Data Suspended Solids.

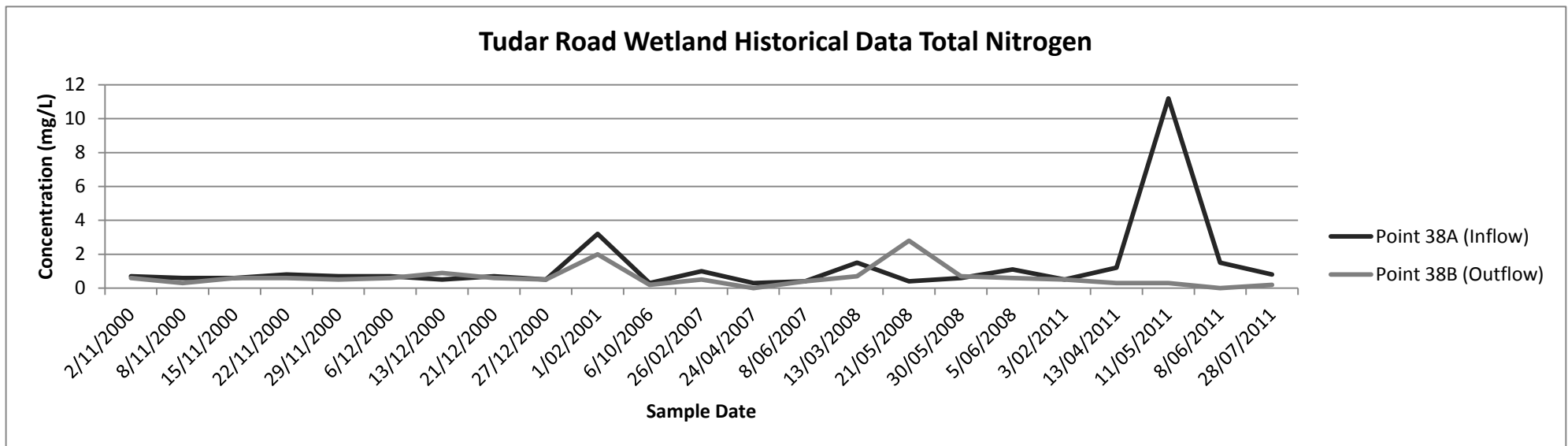


Figure 4.5 Tudor Road Wetland Historical Data Total Nitrogen.

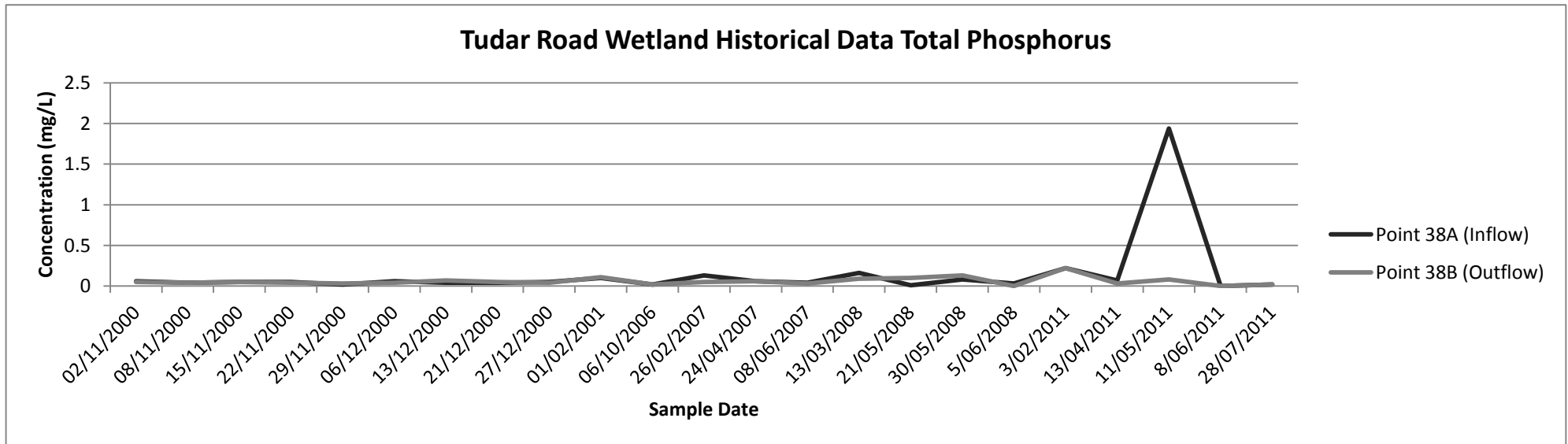


Figure 4.6 Tudar Road Wetland Historical Data Total Phosphorus.

### 4.1.3 Still Creek Detention Basin

Still Creek Detention Basin doesn't appear to conform to the relationship theories presented above to the same extent as the previous sites. For example, cadmium (Fig. 3.43) is the only heavy metal which shows any association with the changing suspended solids (Fig. 3.42) concentration. Copper (Fig. 3.45) and zinc (Fig. 3.46) are the only pollutants which appear to be related to rainfall, though the relationship doesn't conform to the Kayhanian et al (2007) notion, that higher rainfall events achieve lower constituent concentrations, due to a dilution type effect from the excess stormwater. In this instance, the relationship is the opposite and perhaps stormwater has transported quantities of these metals into the system.

Looking at the surrounding land use on Maps 2.25 and 2.21, it can be seen that the catchment is quite large and is dominated by housing areas including, Zone 4- Local Housing and Zone 6- Multiple Dwelling B, as well as the Menai Marketplace and a portion of Menai Road. In this kind of environment, motor vehicle traffic and the weathering of galvanised products could have contributed to the accumulation of copper and zinc on roads and roofs (Wong, 2006). The Menai Marketplace would attract a significant amount of traffic, capable of producing contaminants through direct deposition of abrasion particles and fuel and lubricant leakages (Egodawatta et al., 2009). The fact that vehicles are parked for extended periods in the carpark could very likely lead to a greater concentration of pollutants as fuel and lubricant leakages are allowed to accumulate, along with particles originating from the wear of brakes and tyres. During a rain event this would be transported to Still Creek Detention Basin and could possibly account for the results achieved. Although the weathering of galvanised roofing is a common source of zinc within the urban environment, the majority of buildings in this catchment have tile roofs. It was discovered by Zobrist et al. (2000) however, that tile roofs in Switzerland can still contribute reasonable amounts of zinc to stormwater runoff, as a result of atmospheric deposition, and it is possible that this could be occurring here. Alternatively, the roofing area from the Menai Marketplace represents a significant galvanised surface and weathering of this feature could account for the zinc levels recorded. This would correspond well with the rain events surrounding the sampling period with Van Metre and Mahler (2003) establishing that the first 2.6 mm of rain will mobilise the majority of pollutants deposited on roofs. It is reassuring that Figures 4.7, 4.8 and 4.9 show that, like Mianga Avenue Wetland, the concentrations of copper, lead and zinc reaching the inflow, have reduced over time. This is despite the development of large retail centre south west of the Menai Marketplace and visible on Map 2.21, which could represent a possible



contributor of such pollution to the catchment. Unfortunately, the zoning is undefined on Map 2.24 and therefore a comparison of any zoning changes cannot be made.

The high anomaly recorded for chromium (Fig. 3.44) on 28/7/2011 could be contributed to pollution of the stormwater from any number of domestic products, pesticides and fertilisers, paints or engine parts (Wong, 2006). These could have originated from the residential properties in the catchment. Due to the low flow conditions and long detention times in Still Creek Detention Basin under dry conditions, it is possible that nitrification and denitrification is allowed to occur uninterrupted (Taylor et al., 2005) creating the relationship observed between ammonia (Fig. 3.47), nitrite and nitrate (Fig. 3.48) and total nitrogen (Fig. 3.50). It is possible that the increase in these concentrations on 28/7/2011 from relatively constant values could be attributed to the high rainfall period (Table 3.3) five days previously washing nitrogen-rich material such as fertiliser or animal wastes into the system. Figure 3.51, total phosphorus, certainly suggests that nutrients are entering the system at certain periods and perhaps the vegetation currently growing within the detention basin is insufficient at effectively controlling nutrient loads. This doesn't explain the unusual result achieved for TKN (Fig. 3.49) however. Figures 4.10 and 4.11 indicate that while total nitrogen and total phosphorus levels have fluctuated considerably over time they have remained rather constant.

The high outflow concentrations for *Enterococci* (Fig. 3.53) could be attributed to the fact that a population of ducks frequent the detention basin and tend to congregate in the area where access for sampling is achievable. It is possible that waste material associated with these birds could contribute to higher micro-organism levels in that location (Wong, 2006). Figure 4.12 appears to demonstrate that *Enterococci* concentrations are currently at a very low level compared with past measurements. Further investigation reveals, however, that many of the high counts are associated with intense periods of rainfall where, for example, 45.2 mm of rain fell on the day of the sampling, in the case of 15/11/2000 (BOM, 2011). This increased runoff would be responsible for transporting greater quantities of bacteria to the system (Converse et al., 2011) and could account for these measurements. The most recent sampling dates do not correspond with such periods of rainfall and therefore this could explain the lower levels depicted. In other instances, such as 26/6/1997, *Enterococci* levels are not correlated with high precipitation and therefore other causes are likely. Perhaps waste material, including sediment, was discharged into the waterway at some point and this promoted the growth in bacteria recorded.

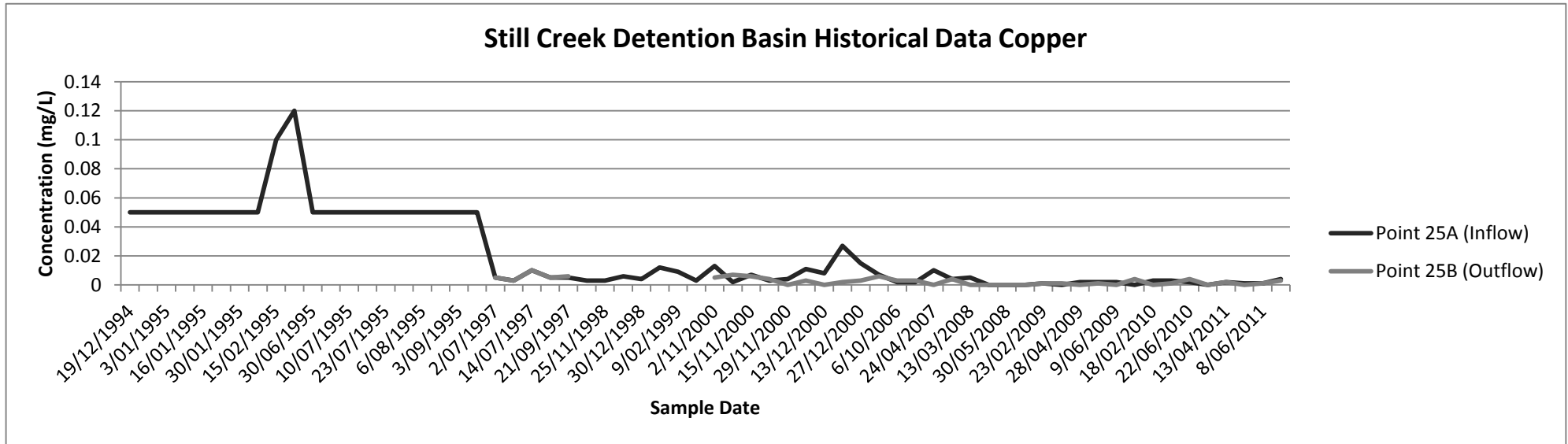


Figure 4.7 Still Creek Detention Basin Historical Data Copper.

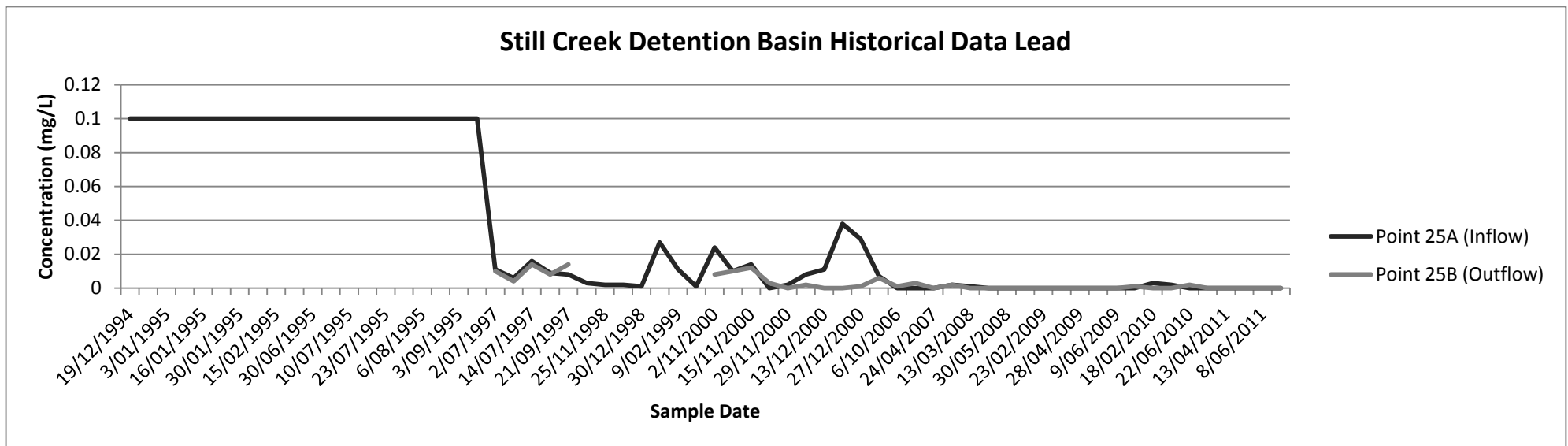


Figure 4.8 Still Creek Detention Basin Historical Data Lead.

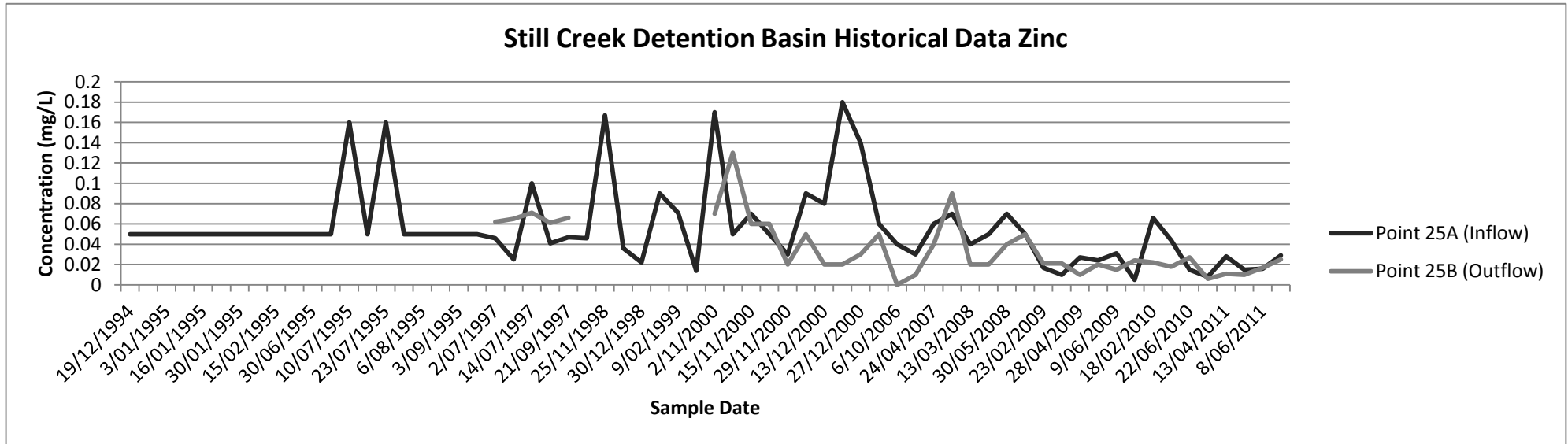


Figure 4.9 Still Creek Detention Basin Historical Data Zinc.

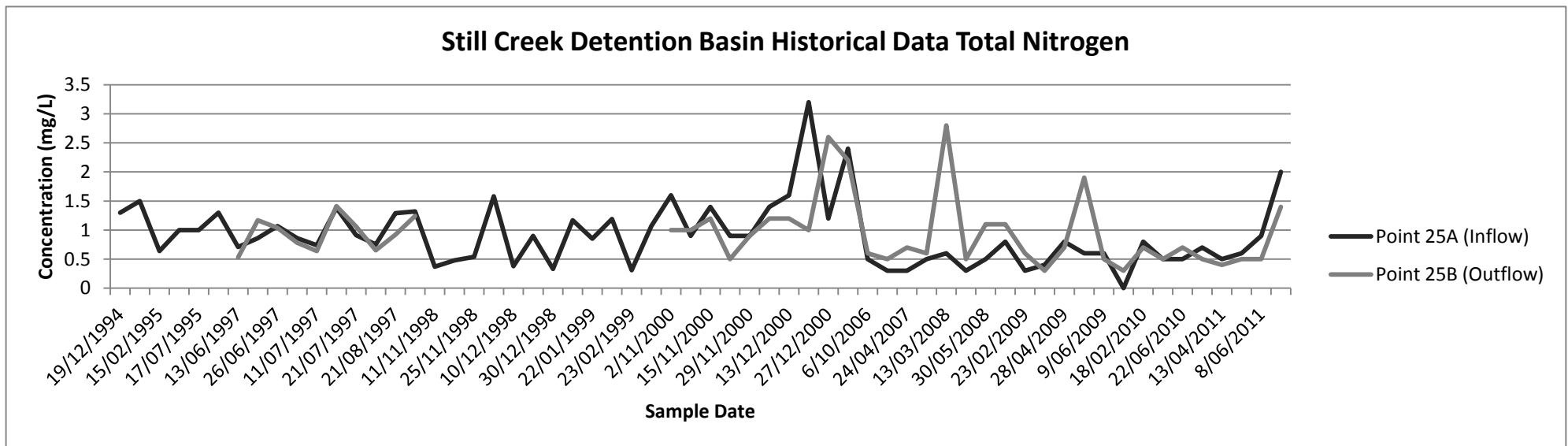


Figure 4.10 Still Creek Detention Basin Historical Data Total Nitrogen.



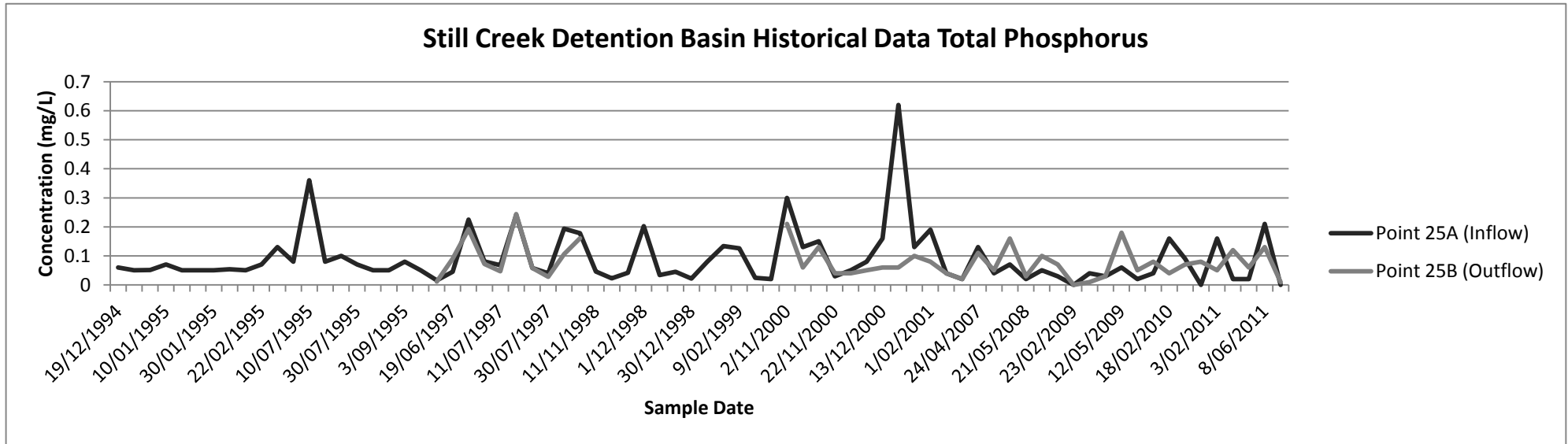


Figure 4.11 Still Creek Detention Basin Historical Data Total Phosphorus.

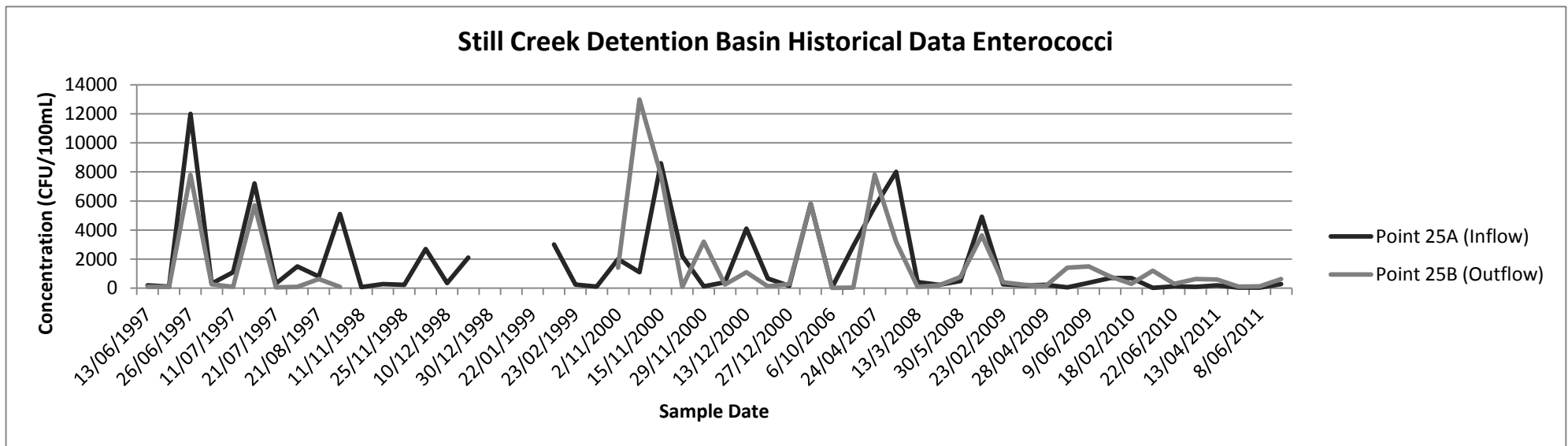


Figure 4.12 Still Creek Detention Basin Historical Data *Enterococci*.

#### 4.1.4 Burnum Burnum Detention Basin

As with Tudar Road Wetland, Burnum Burnum Detention Basin demonstrates an apparent relationship between suspended solids (Fig. 3.58) and the heavy metals examined, explained above by the fact that the majority of heavy metals in stormwater are attached to suspended sediment (Herngren et al., 2005). Unlike Tudar Road, Burnum Burnum does not incorporate any housing areas into its catchment, as shown by Maps 2.26 and 2.30, and 2.27 and 2.31. In fact, the water only drains from Woronora Bridge where the main pollutant source would be motor vehicles. The high concentration of suspended solids at the inflow on 13/4/2011 corresponds with the raised values for all other constituents with the exception of arsenic (Fig. 3.59), nitrite and nitrate (Fig. 3.67) and total phosphorus (Fig. 3.70). A small rain event on 11/4/2011, prior to sampling on 13/4/2011, could possibly account for the higher suspended solids under the relationship presented by Kayhanian et al. (2007) discussed above. The various peaks in suspended solids, illustrated in Figure 4.13 can also be associated with rainfall events (BOM, 2011). The relative differences in the sizes of these peaks indicates that not all rain events have the same washoff potential and other factors may be involved in determining the resultant suspended solids concentration. For example it was found by Vaze and Chiew (2002) that common storms only remove a small proportion of the total surface pollutant load from roads. Furthermore, they concluded that long antecedent dry periods result in greater pollutant build-up which could then be mobilised by a large storm event, resulting in higher constituent concentrations. For this study, rainfall data was considered for up to five days preceding the sampling event, although examining this information over a greater period may reveal more clearly the role that rainfall plays in determining pollutant loads. Burnum Burnum is similar to Tudar Road in the sense that under normal conditions the raised heavy metal values are rather small. Figures 4.13, 4.14, 4.15 and 4.16 show a good correlation between suspended solids and the concentration of copper, lead and zinc over time.

The results for ammonia (Fig. 3.66), nitrite and nitrate (Fig. 3.67) would suggest that nitrification and denitrification is occurring effectively. This notion is supported by the fact that Burnum Burnum Detention Basin is characterised by low flow conditions and long detention times which, as mentioned previously, promotes the nitrification and denitrification process (Taylor et al., 2005). Figures 4.17 and 4.18 demonstrate that total nitrogen and total phosphorus are usually at quite low concentrations. Due to the fact that riparian vegetation is not a major feature at this site, the low nutrient levels would suggest that the Woronora Bridge is not a significant source of such pollution.

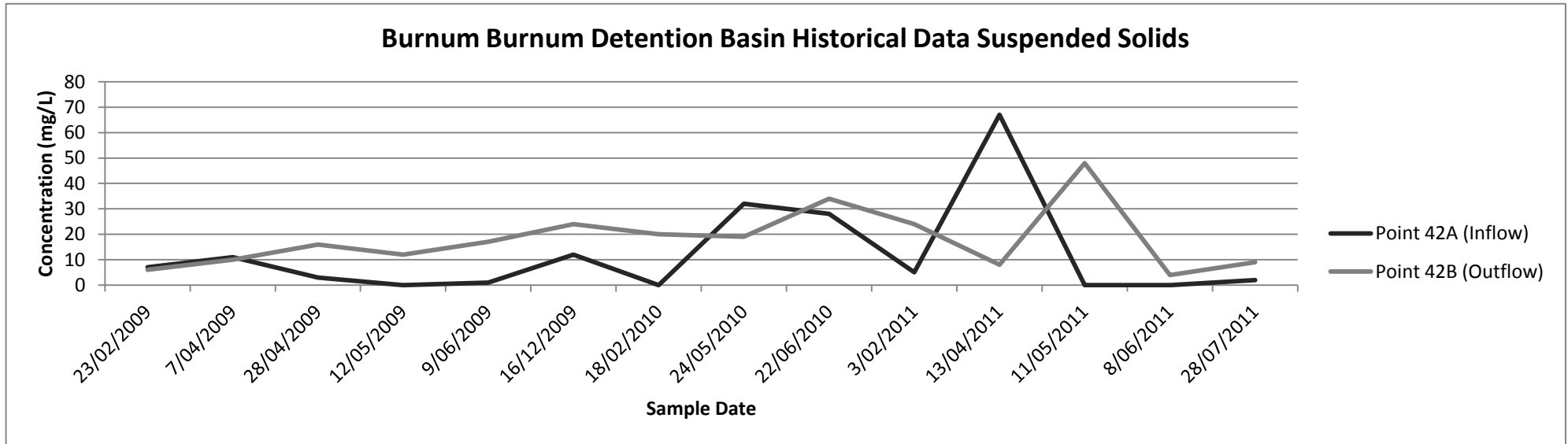


Figure 4.13 Burnum Burnum Detention Basin Historical Data Suspended Solids.

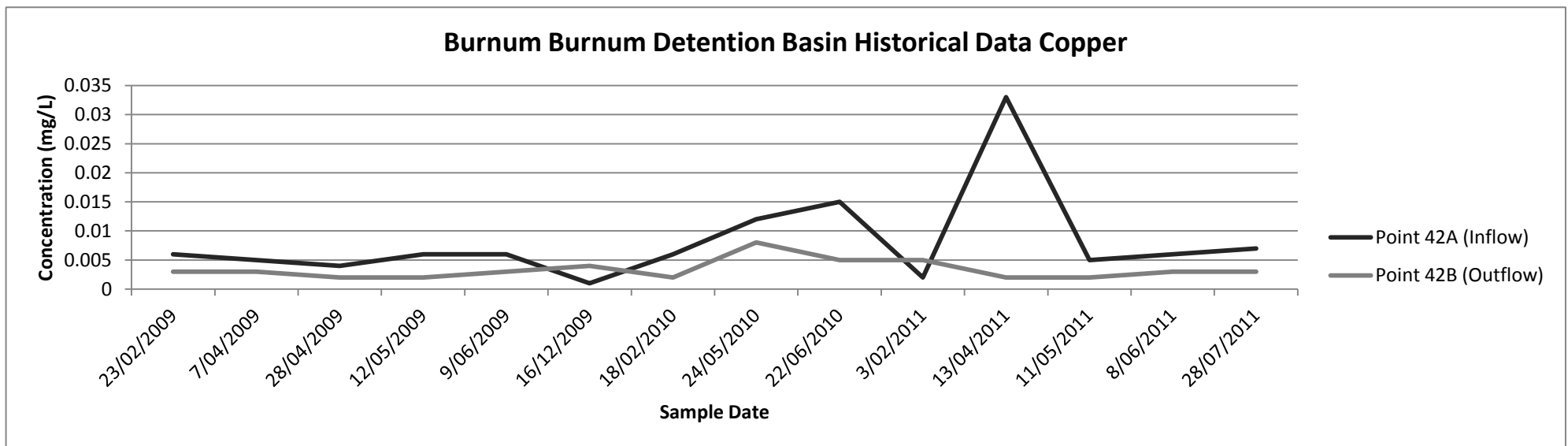


Figure 4.14 Burnum Burnum Detention Basin Historical Data Copper.



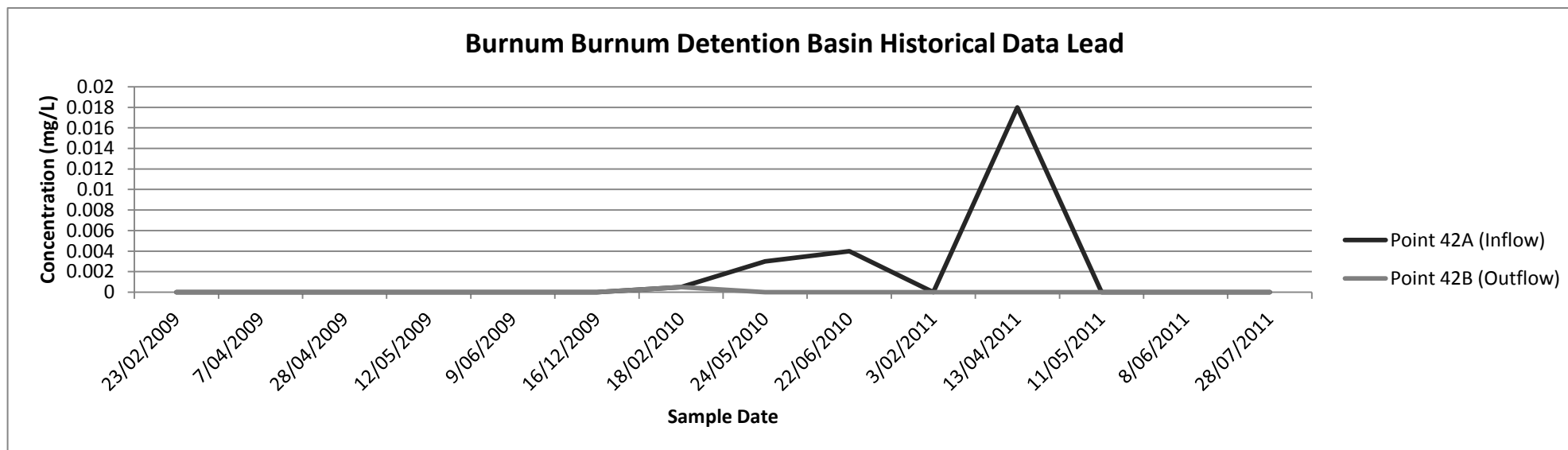


Figure 4.15 Burnum Burnum Detention Basin Historical Data Lead.

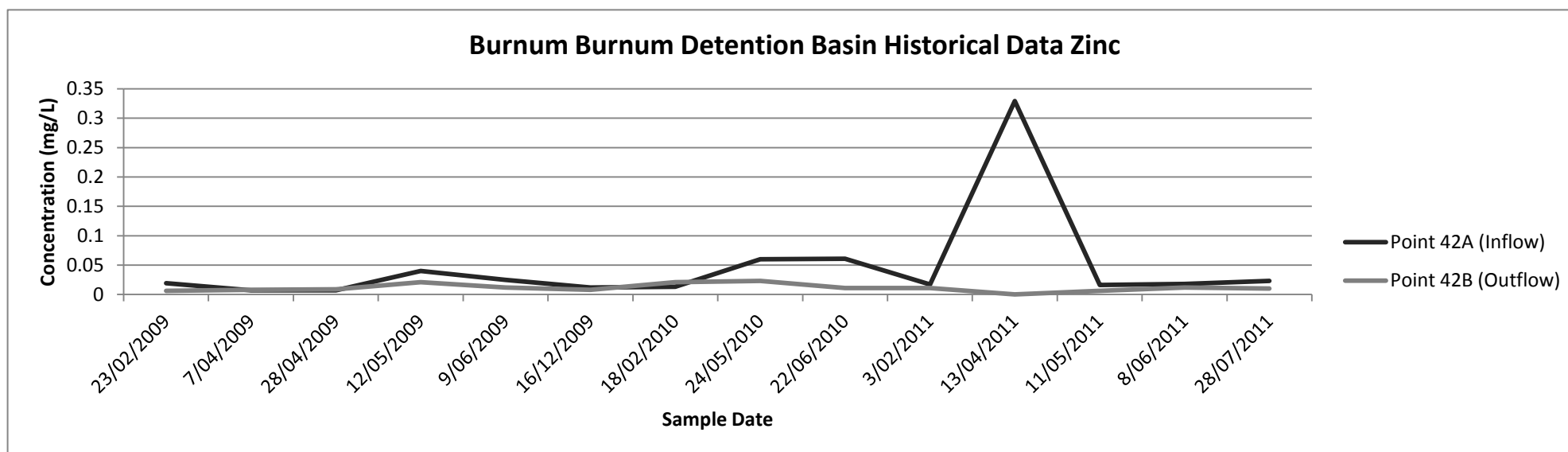


Figure 4.16 Burnum Burnum Detention Basin Historical Data Zinc.

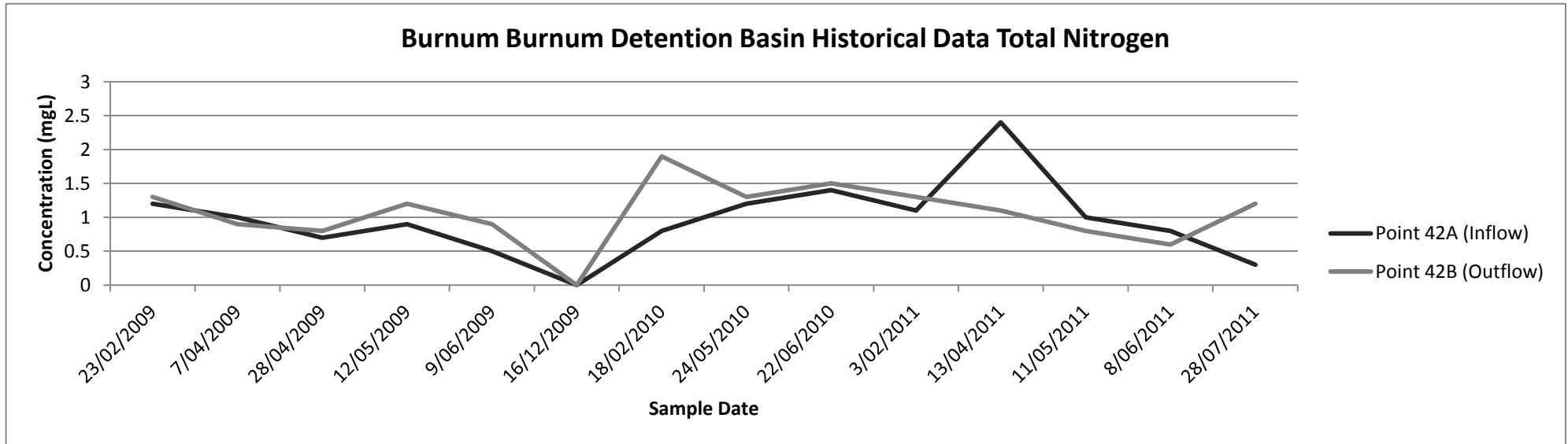


Figure 4.17 Burnum Burnum Detention Basin Historical Data Total Nitrogen.

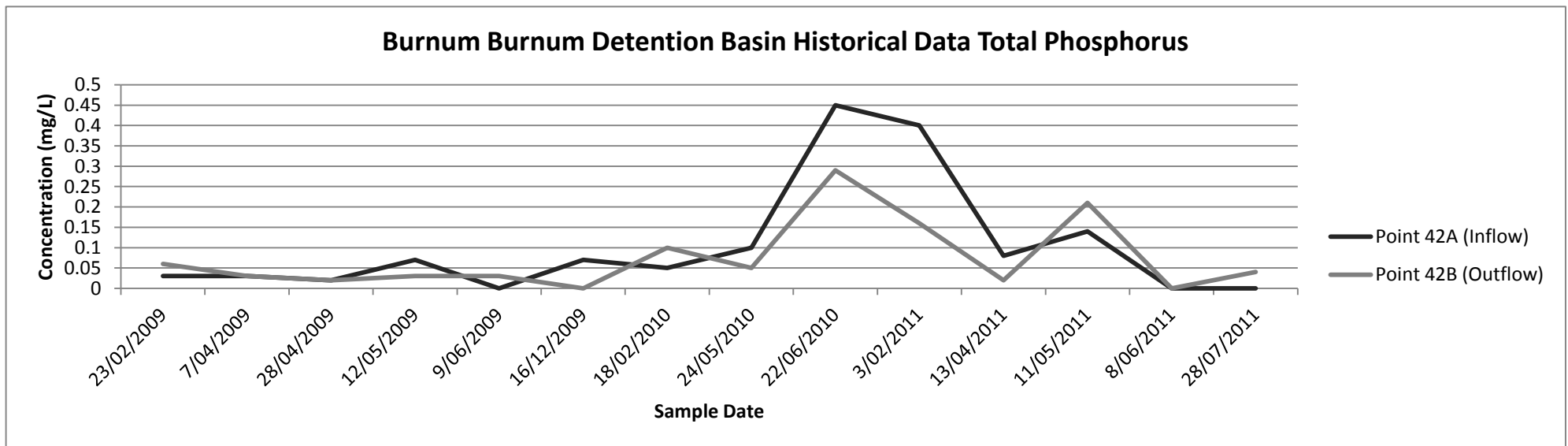


Figure 4.18 Burnum Burnum Detention Basin Historical Data Total Phosphorus.

#### 4.1.5 Gunnamatta Bay GPT

The suspended solids results (Fig. 3.77) and heavy metal concentrations for Gunnamatta Bay GPT cannot be explained by the transport of pollutants on suspended sediment as detailed by Herngren et al. (2005). The concentrations of heavy metals do not appear to be related to rainfall either and thus cannot be explained by Kayhanian et al.'s (2007) notion of stormwater dilution. Examining Maps 2.19 and 2.15, it can be seen that the catchment for this GPT is dominated by a variety of housing types including Zone 4- Local Housing, Zone 5- Multiple Dwelling A and Zone 6- Multiple Dwelling B as well as Zone 8- Urban Centre. Comparing these with Maps 2.18 and 2.14, it can be seen that catchment land use has seen little change since 2000/2001. As with Still Creek Detention Basin, this represents a relatively large and highly urbanised catchment, easily capable of contributing various concentrations of heavy metals to the stormwater runoff from domestic products and motor vehicle use. The various fluctuations in the concentrations of these metals over the course of the sampling period would suggest that no constant and reliable source exists and delivery to the system is variable. Pollutant build-up and washoff mechanisms could also account for variable delivery through inconsistent transport by storm events of differing sizes with differing lengths of antecedent dry period (Egodawatta et al., 2009). It is also worth considering that some heavy metals can originate from recreational boating activities, particularly copper, as shown by Warnken et al. (2004). Many of the anti-fouling paints introduced to replace tributyltin (TBT) based paints are copper based and copper, while being much less toxic than TBT, can still cause problems. It is comforting to note that in the majority of instances the metals have been retained by the GPT and are reduced or absent in the outflow. It is also comforting to note that copper, lead and zinc concentrations coming into the GPT have decreased over time, as illustrated by Figures 4.19, 4.20 and 4.21. This would suggest that copper based anti-fouling paints are not playing a major role in the delivery of copper to the system, as this product's use would potentially have increased over the same time period, due to developed nations such as the USA and Australia banning TBT paints between 1982 and 1990 (Warnken et al., 2004).

The close proximity of Tonkin Oval to the GPT could possibly result in the inflow of nutrients to the system from field maintenance activities and this could in turn account for the varying nutrient concentrations. Examining Figures 4.22 and 4.23 it can be seen that total nitrogen and total phosphorus have remained largely constant since 1994. *Enterococci* (Fig. 3.91) do appear to correspond with rainfall, with higher *Enterococci* counts associated with



periods of higher rainfall (Table 3.5). The increased runoff from the catchment could be responsible for collecting greater concentrations of animal waste, which is recognised as the major source of micro-organisms in urban catchments (Wong, 2006), and delivering this to the GPT. Indeed, it is recognised by Converse et al. (2011), that stormwater entrains faecal bacteria that has accumulated following the last rain event, creating bacteria levels which can be in excess of 1000 times above base flow conditions. Figure 4.24 shows a good correlation between past rainfall events (BOM, 2011) and high *Enterococci* readings, with peaks on the graph corresponding with high rainfall on the day of the sampling, therefore supporting this concept.

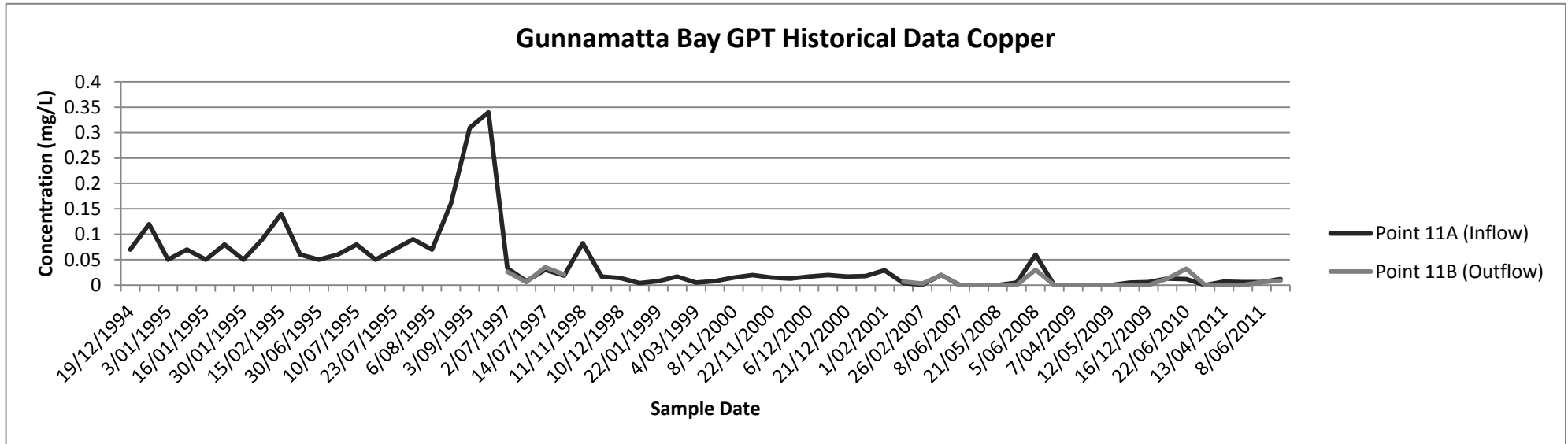


Figure 4.19 Gunnamatta Bay GPT Historical Data Copper.

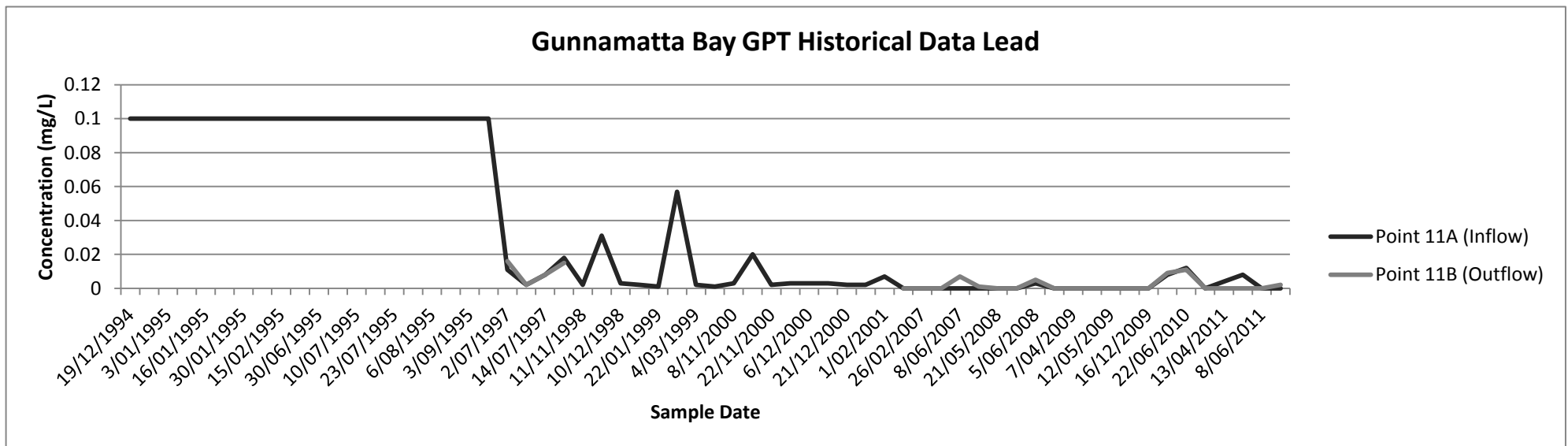


Figure 4.20 Gunnamatta Bay GPT Historical Data Lead.

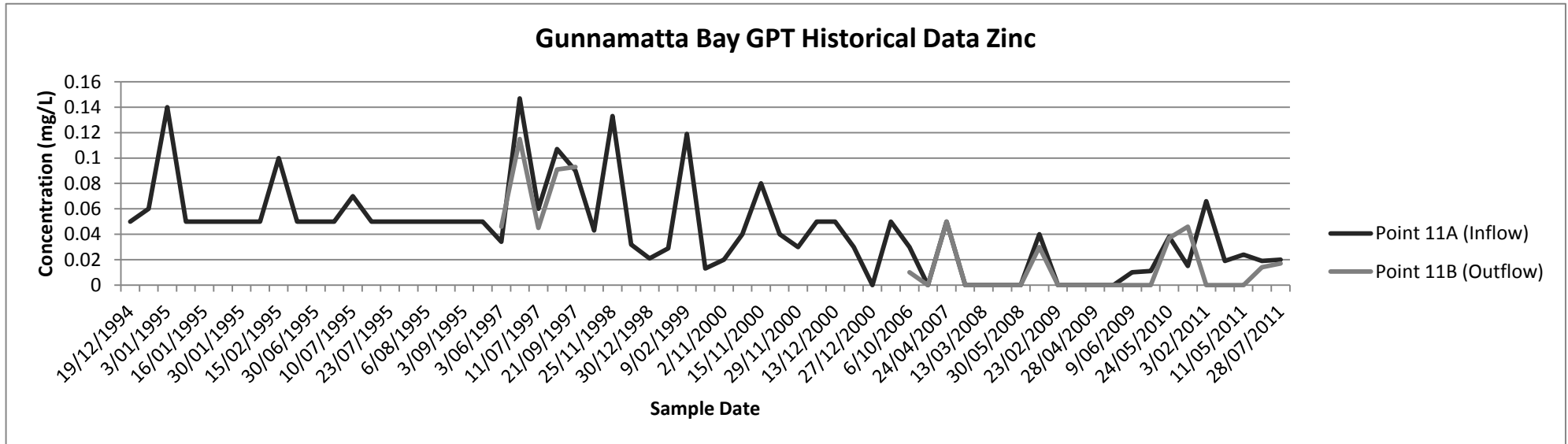


Figure 4.21 Gunnamatta Bay GPT Historical Data Zinc.

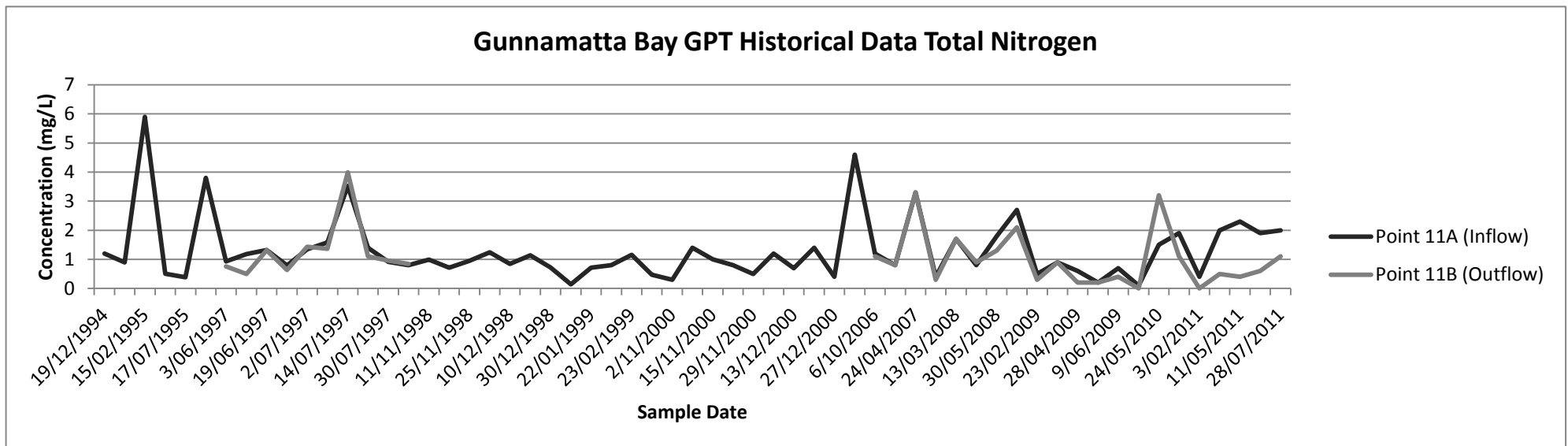


Figure 4.22 Gunnamatta Bay GPT Historical Data Total Nitrogen.



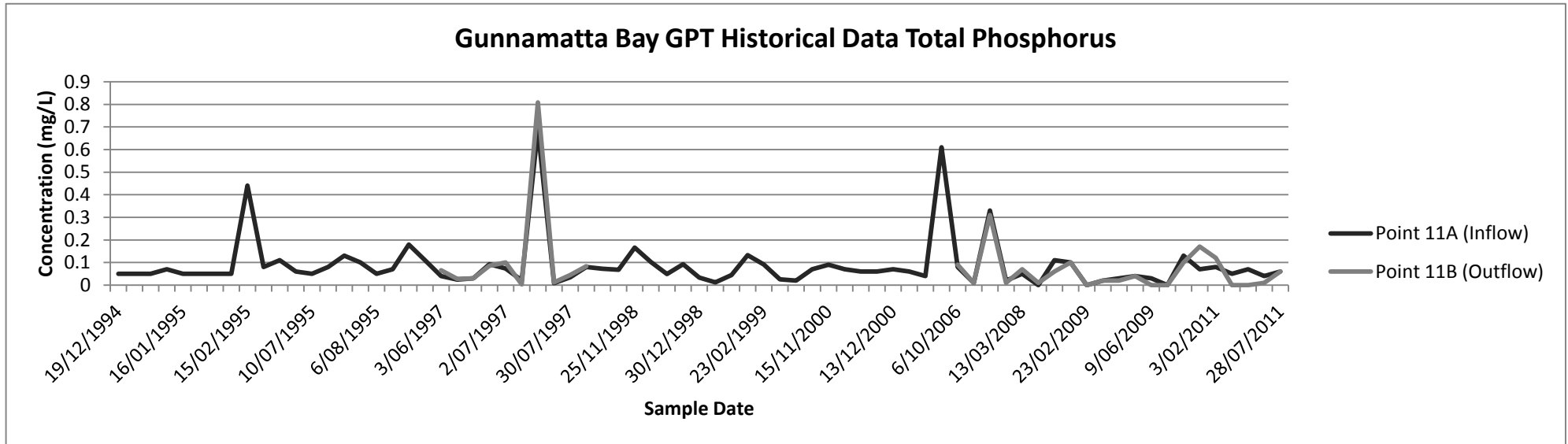
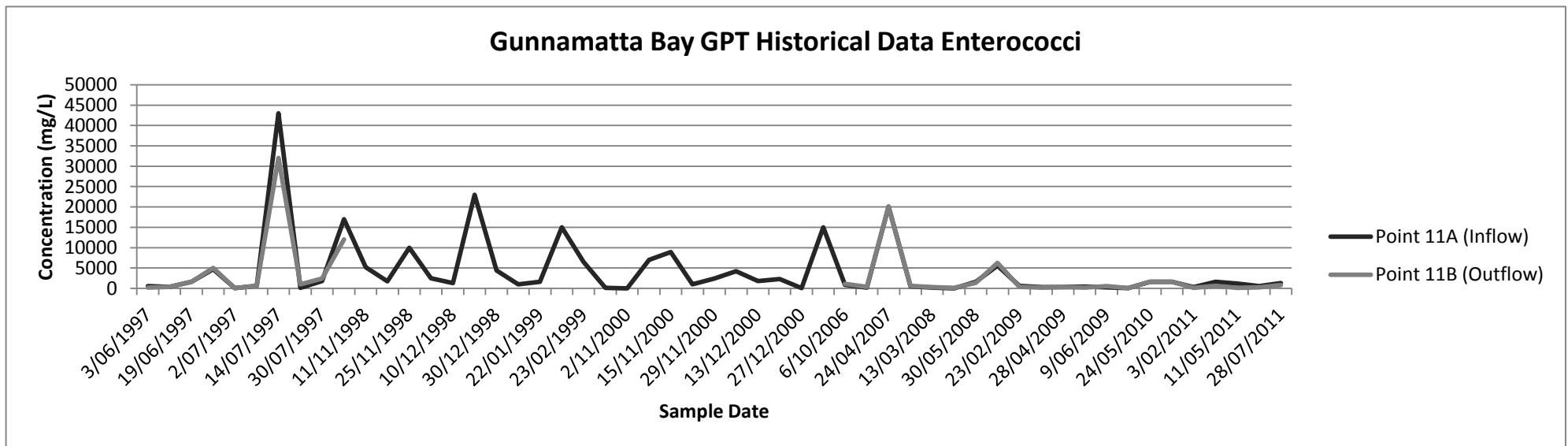


Figure 4.23 Gunnamatta Bay GPT Historical Data Total Phosphorus.

Figure 4.24 Gunnamatta Bay GPT Historical Data *Enterococci*.

#### 4.1.6 Cronulla Beach GPT

Cronulla Beach GPT also displays little correlation between suspended solids (Fig. 3.96) and heavy metals under the attachment of pollutants to sediment surfaces. Copper (Fig. 3.100) and zinc (Fig. 3.103) are perhaps the only exception to this with the inflow concentrations demonstrating changes in accordance with the suspended solids. Maps 2.13 and 2.8, demonstrate that the catchment delivering water to Cronulla Beach GPT is much smaller than that draining into Gunnamatta Bay GPT and as shown by Maps 2.12 and 2.9, hasn't changed greatly since 2000/2001. The catchment is similar to Gunnamatta Bay GPT in the sense that it is highly urbanised with Zone 6- Multiple Dwelling B and Zone 8- Urban Centre representing major land uses. Like Gunnamatta Bay, Figures 4.25 and 4.26 show a reduction in copper and lead in the catchment since 1994, though the same cannot be said for zinc (Fig. 4.27) which appears to have remained relatively constant.

Similar to the Gunnamatta Bay GPT catchment, this catchment includes Zone 13- Public Open Space where runoff could possibly contribute to nutrient levels. In addition, the Cronulla RSL Memorial Club is one particular source of nutrient runoff through the maintenance of their bowling greens (Kohler et al., 2004). Of interest is the gradual fall in ammonia (Fig. 3.104) and TKN (Fig. 3.106) concentration which presumably has resulted in the rapid drop in nitrite and nitrate (Fig. 3.105) and total nitrogen (Fig. 3.107) concentrations on 28/7/2011. A reduction in total phosphorus (Fig. 3.108) was also observed. It is possible that the maintenance of gardens and grounds in an urban environment, through fertiliser use and irrigation, is conducted more commonly during warmer months and perhaps as the sampling period progressed into cooler periods this was a less common occurrence, therefore reducing the nutrient supply in the catchment. The relationship between evaporation and runoff is an important consideration in terms of the overall impact of these activities. Greater runoff could result in increased transport of nutrients to the GPT while higher rates of evaporation are more likely to contribute to the accumulation of pollutants on and within catchment surfaces. In addition, seasonal differences in rainfall could potentially account for changes in nutrient pollution. During periods of low rainfall, delivery to the GPT could be reduced despite constant or increased use of fertilisers within the catchment. Figures 4.28 and 4.29 do not indicate seasonal changes in total nitrogen and total phosphorus, though the sampling dates are not particularly conducive to observing such a pattern. They do show that over time these constituents have remained largely constant. Note, that one very high inflow value was excluded from Figure 4.29 to improve its legibility.

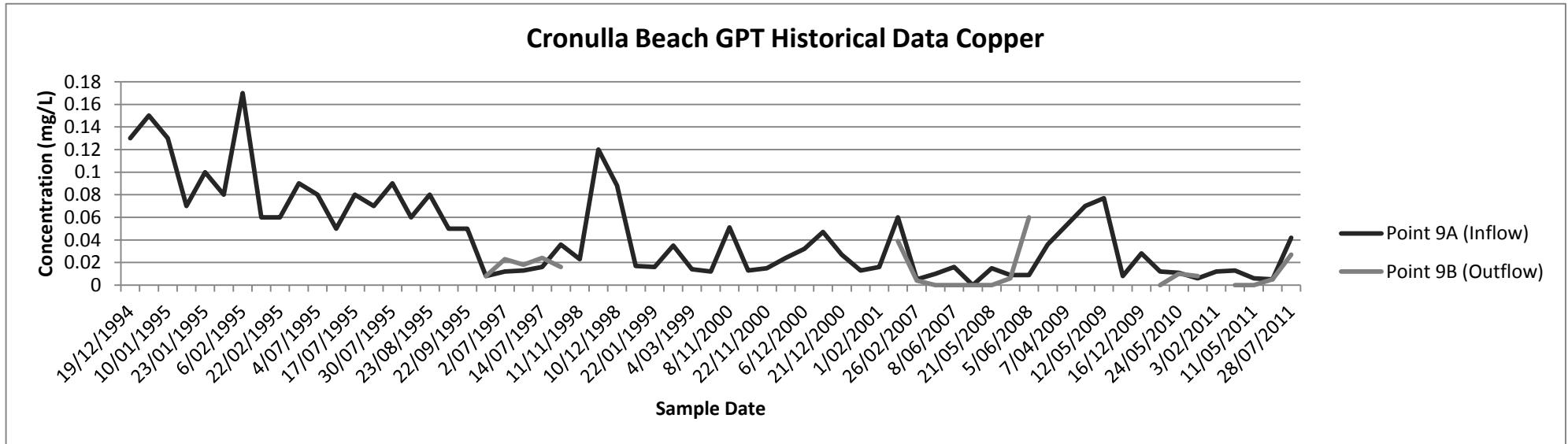


Figure 4.25 Cronulla Beach GPT Historical Data Copper.

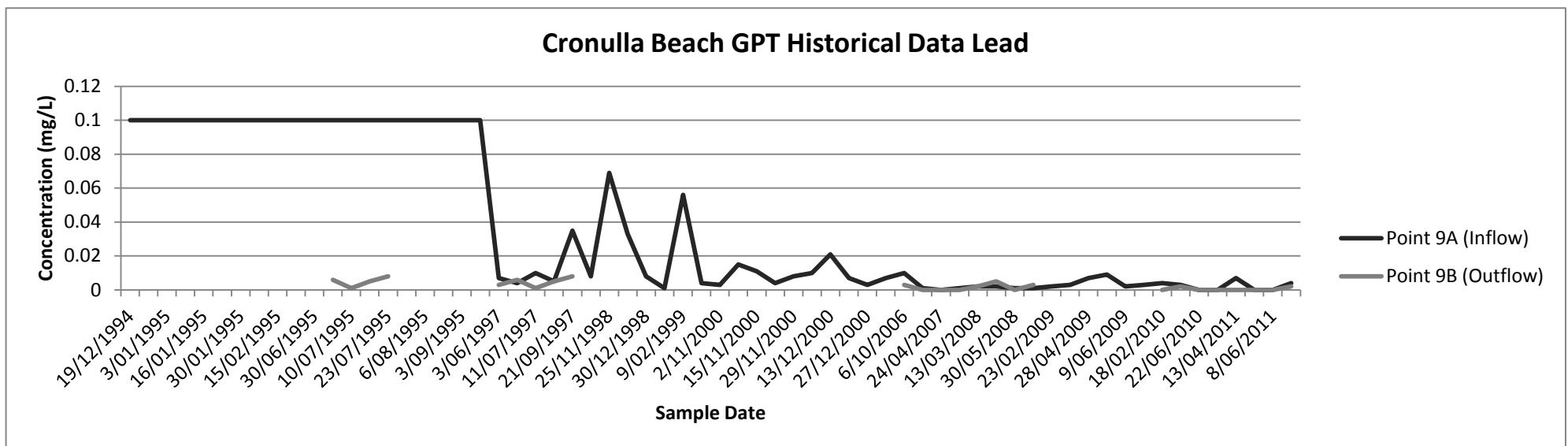


Figure 4.26 Cronulla Beach GPT Historical Data Lead.



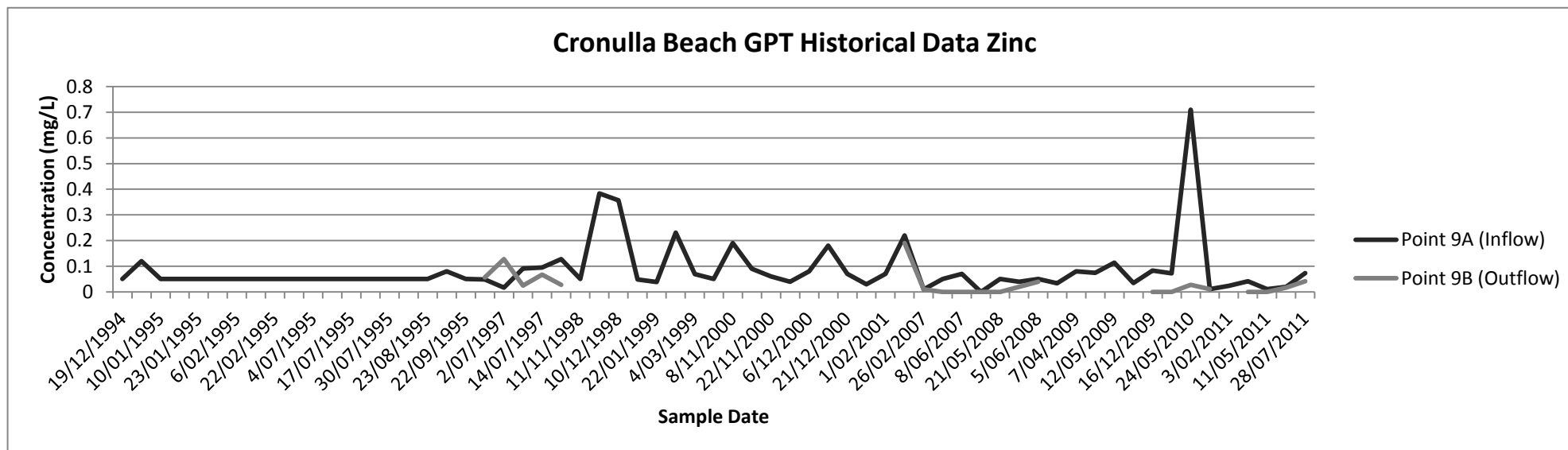


Figure 4.27 Cronulla Beach GPT Historical Data Zinc.

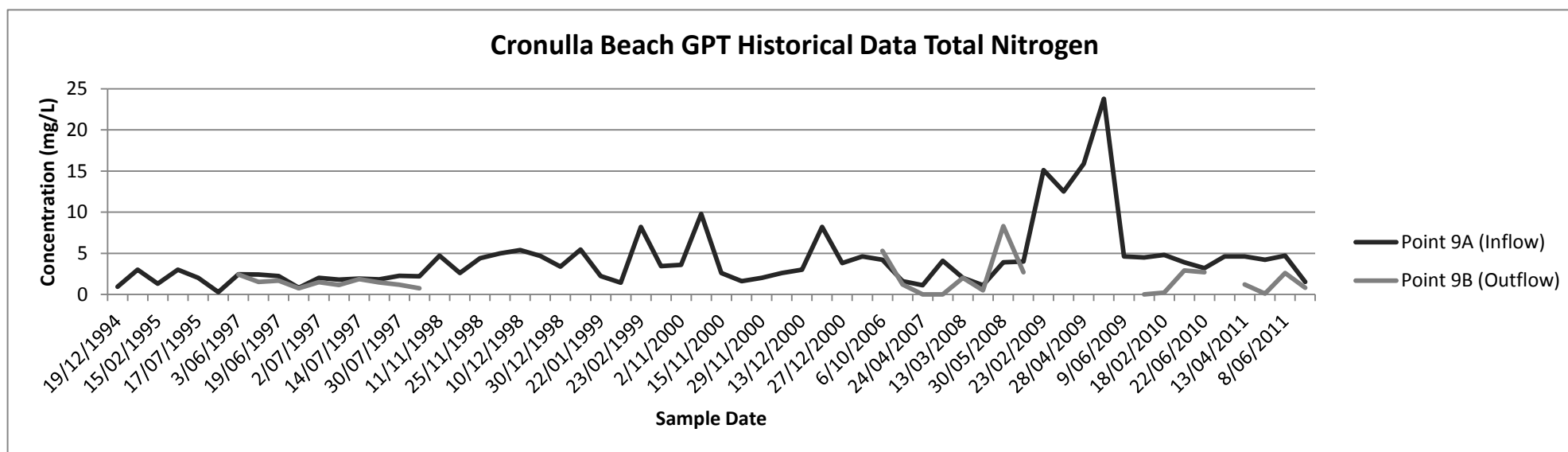


Figure 4.28 Cronulla Beach GPT Historical Data Total Nitrogen.

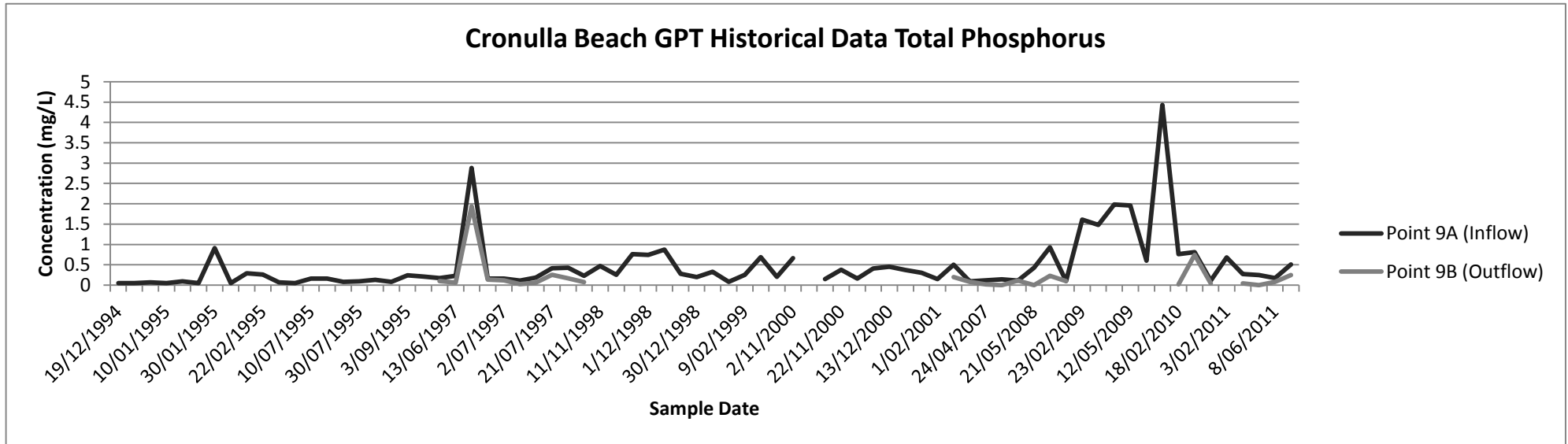


Figure 4.29 Cronulla Beach GPT Historical Data Total Phosphorus. Note excluded inflow value = 45mg/L on 8/11/2000.

## 4.2 Impact of Land Use and Weather Events on Sediment

The sediment analysis demonstrates how in most cases the inflow point of the SQIDs is characterised by larger grade sand and gravel sediment, while at the outflow there is a greater concentration of finer sediment such as silt and clay. This represents the expected outcome from sites such as Mianga Avenue Wetland, Burnum Burnum Detention Basin and Still Creek Detention Basin which have large detention basin systems that will encourage coarse sediment to settle out at the inflow while finer sediment will continue in suspension to the outflow (SADPLG, 2010). This fine sediment could later become remobilised if a disturbance such as a high flow event is introduced to the system. This was observed at all sites with the exception of Tudar Road Wetland and Gunnamatta Bay GPT. As outlined above, sampling difficulties were responsible for the anomaly at Tudar Road Wetland. The result for Gunnamatta Bay GPT can be explained by the fact that the outflow for this site is situated at the end of Gunnamatta Bay and tidal effects could be responsible for transporting and concentrating sand sized sediment in this location (Fiechter et al., 2006). In some instances a high quantity of organic matter was collected along with the sediment sample and this was subsequently included in the sediment analysis procedure. As a result, some of this organic matter could have been counted as coarse sediment, thereby obscuring the results somewhat. In order to eliminate this problem the samples could have been treated with hydrogen peroxide (Leifeld and Kogel-Knabner, 2001) which would have broken down and oxidised the organics, or heavy liquid separation (Dawson and Billett, 1997) could have been employed. This was not undertaken as it was not considered necessary for this project's purpose and scope.

The geology maps introduced in Chapter 2 illustrate that the surrounding geology is largely very similar for all sites studied. The dominant geology encountered at all sites was the Hawkesbury Sandstone either in the form Rh, which is recognised as medium to coarse-grained quartz sandstone, or Rhs, this being claystone, siltstone and laminite (see Appendix 1). Rh was the major form at Cronulla Beach GPT (Map 2.10), Tudar Road Wetland (Map 2.34) and Burnum Burnum Detention Basin (Map 2.28) while Rhs was most prevalent at Mianga Avenue Wetland (Map 2.4) and Still Creek Detention Basin (Map 2.22). Gunnamatta Bay GPT (Map 2.16) displayed approximately 50% share of both major lithologies. Of relevance is the extensive portion of man-made fill present within the Cronulla Beach GPT catchment. This could potentially be a significant source of pollution from runoff depending upon the quality of the fill sourced for this site. As noted in Appendix 1 such fill could



incorporate industrial and household waste which is likely to contain heavy metals and excess nutrients. Further investigation would be required to fully determine the possible impact of this material. In addition, Burnum Burnum Detention Basin is unusual in that it only drains from the Woronora Bridge. As a result of this, the impact of surrounding geology would quite likely be limited, as runoff would not have an opportunity to travel over the natural ground surface.

While the surrounding geology was very similar across all sites studied, the soil types encountered varied depending upon the SQID's location. Cronulla Beach GPT (Map 2.11) and Gunnamatta Bay GPT (Map 2.17) were both surrounded by GyMEA and Disturbed Terrain. Due to the close proximity of these two sites, this is to be expected. Tudar Road Wetland (Map 2.35) and Burnum Burnum Detention Basin (Map 2.29) are also situated close together and displayed similar soil types with Burnum Burnum Detention Basin characterised by both GyMEA and Hawkesbury and Tudar Road Wetland dominated by GyMEA alone. Mianga Avenue Wetland (Map 2.5) only presented one soil type, Faulconbridge while Still Creek Detention Basin (Map 2.23) presented both Lucas Heights and Blacktown. The soil from these areas could be incorporated into stormwater during runoff from lawns and building sites. The contribution of the surrounding soil to Burnum Burnum Detention Basin is likely to be less, compared with other SQIDs, due to the limited exposure of this site to any large soil bodies. The possibility of transport of sediment by wind and motor vehicle traffic could, however, account for some of the suspended sediment encountered, although under these conditions the soil type may not match the surrounding area as it could have originated from another catchment.

#### **4.3 Most Effective Stormwater Quality Improvement Devices**

This study aimed to identify the relative performance efficiencies of the six SQIDs examined in order to assess which were the most effective in improving the quality of stormwater. To achieve this, the water quality results were compared with two published guideline values for various contaminants, these being the Australian Runoff Quality Guidelines (2006) and the ANZECC *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000). In addition, water quality values from two control sites within the Sutherland Shire were employed, to give an indication of the background concentrations present in the catchments studied. Mode values, taken from data collected at these control

sites between 1994 and 2010, were used as the representative background concentrations of the relevant constituents. It was decided that the mode data represented the most accurate measure, rather than the mean, due to larger values, possibly from storms, impacting upon the distribution of the mean. Using the Australian Runoff Quality Guidelines (2006), enrichment factor tables were produced to clearly illustrate breaches in water quality relative to the guidelines. The Australian Runoff Quality Guidelines were employed as they were considered the most appropriate, having been devised specifically for urban stormwater runoff. The ANZECC guidelines by comparison, are more concerned with the quality of natural waters and therefore the guideline values are lower, which could unrealistically amplify the apparent contamination of the runoff.

The Australian Runoff Quality Guidelines enrichment factor tables show that Mianga Avenue Wetland (Table 4.1), Gunnamatta Bay GPT (Table 4.5), Cronulla Beach GPT (Table 4.6) and Tudar Road Wetland (Table 4.2) all operate with a reasonable degree of efficiency and produce an outflow, which in most instances, is of a better quality than the inflow. Of these four sites, Tudar Road is possibly the most effective with the outflow values exceeding the guidelines on only 4 occasions compared to 14 occasions for Mianga Avenue Wetland. In terms of the GPTs, Cronulla Beach GPT outflow values exceeded the guidelines on 10 occasions while Gunnamatta Bay GPT did so on 8 occasions. Unfortunately, the result for Cronulla Beach GPT is uncertain due to the lack of outflow values for 3/2/2011. The apparent efficiency of Gunnamatta Bay GPT is surprising, given the fact that it is of a relatively simple design. Tudar Road Wetland by comparison, is a detailed design and it is, therefore, expected that it would perform better. It is this for this reason that the result for Mianga Avenue Wetland is surprising, considering that its design does include a substantial sediment trap and wetland basin. The efficiency of Mianga Avenue Wetland is better shown by examining the number of instances where the outflow concentration exceeds the inflow. In the case of Mianga Avenue Wetland, this occurred 5 times which is equal to the result for Gunnamatta Bay GPT, while Tudar Road Wetland and Cronulla Beach GPT returned 3 and 2 instances respectively. Using this approach, it becomes apparent that perhaps the catchment draining into Mianga Avenue Wetland is more polluted than the others, though the historical data suggests that it has improved since 1994, and while the treatment system installed does a reasonable job of improving the quality of water leaving the wetland, it cannot treat it to the quality stipulated in the guidelines. This does not indicate a failure on the part of the SQID, rather it indicates a need to address pollution in the catchment or increase the treatment

capabilities of the system. Reviewing Table 3.1, it can be seen that those constituents not included in Table 4.1 also demonstrate relatively high values which would suggest that the actual pollutant loads support the concept of greater amounts of pollution at Mianga Avenue Wetland. Interestingly, Cronulla Beach GPT (Tables 3.6 and 4.6) appears to be the most polluted catchment with inflow concentrations exceeding those for Mianga Avenue by a greater amount in a number of instances.

Burnum Burnum Detention Basin and Still Creek Detention Basin by comparison are poorly functioning devices as shown by Tables 4.3 and 4.4. It can be seen that for Burnum Burnum the outflow concentration exceeds the guideline on 11 occasions and it exceeds the inflow value on 12 occasions. The result is similar for Still Creek with the outflow concentration exceeding the guideline on 8 instances and it exceeds the inflow concentration on 11 instances. Comparing the actual inflow concentrations from these two sites (Tables 3.3 and 3.4) with the inflow concentrations from Mianga Avenue Wetland (Table 3.1) or Cronulla Beach GPT (Table 3.6) it can be seen that they are relatively less polluted catchments, though they have a greater constituent inflow concentration than Tudar Road (Table 3.2), for example. This further demonstrates their ineffectiveness and highlights that operating issues are likely to be a problem at these sites.

Enrichment factor tables were also produced for the control site mode values to demonstrate changes above the background concentrations. Mianga Avenue Wetland (Table 4.7), Gunnamatta Bay GPT (Table 4.11) and Cronulla Beach GPT (Table 4.12) are within the Port Hacking River catchment and therefore share the same control site at Kangaroo Creek, while Tudar Road Wetland (Table 4.8), Still Creek Detention Basin (Table 4.9) and Burnum Burnum Detention Basin (Table 4.10) are encompassed by the Georges River catchment and the control site at Woronora River. Tables 4.7 to 4.12 show that the pollutant concentrations at all sites are well above the background levels, particularly in the case of total nitrogen and total phosphorus which show dramatic increases above background at all six sites. Interestingly, Tudar Road Wetland (Table 4.8) displayed very high total nitrogen increases while total phosphorus was significantly smaller. This can in part be attributed to the fact that the background concentration for total nitrogen is much smaller than that for total phosphorus, however, it demonstrates the potential for high total nitrogen pollution within the urban environment. The potential for heavy metal contamination is demonstrated by the results for Mianga Avenue Wetland, Gunnamatta Bay GPT and Cronulla Beach GPT which show



significant increases in arsenic, copper, lead and zinc. The same level of increase was not observed for Tudar Road Wetland, Still Creek Detention Basin and Burnum Burnum Detention Basin, although this could possibly be due to higher background concentrations of these metals at the Woronora River control site. Ultimately, the control site data illustrates that the urban environment is capable of contributing significant quantities of contaminants to stormwater which, as a result, reduces the quality of runoff from these environments. None of the SQIDs studied were capable of returning the quality of runoff to background levels which is to be expected. The purpose of such devices is to improve the stormwater quality and as demonstrated by, Mianga Avenue Wetland (Table 4.1), Gunnamatta Bay GPT (Table 4.5), Cronulla Beach GPT (Table 4.6) and Tudar Road Wetland (Table 4.2), this is occurring at these sites. Although, it is difficult to specify which site is operating the most effectively, all four of these sites were designed specifically for stormwater treatment which would suggest that the installation of targeted infrastructure is essential for SQID success.

Table 4.1 Mianga Avenue Wetland Australian Runoff Quality (ARQ) Enrichment Factors.

| ALS Workgroup Number      |       |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|---------------------------|-------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date               |       |                                     |   | 03/02/2011         | 03/02/2011          | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 08/06/2011         | 08/06/2011          | 28/07/2011         | 28/07/2011          |
| Sampling Site             |       |                                     |   | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) |
|                           | Units | Laboratory Limit of Reporting (LOR) | Australian Runoff Quality Guidelines (2006) |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| Suspended Solids (SS)     | mg/L  | 1                                   | 25  | NC <sup>B</sup>    | 0.6                 | 0.2                | 0.76                | 0.72               | 0.4                 | 0.4                | NE <sup>A</sup>     | 0.24               | 0.08                |
| Cadmium                   | mg/L  | 0.0001                              | 0.0004                                      | NC <sup>B</sup>    | 3.75                | NE <sup>A</sup>    | 16.5                | 0.25               | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Chromium                  | mg/L  | 0.001                               | 0.01  | NC <sup>B</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.1                | NE <sup>A</sup>     |
| Copper                    | mg/L  | 0.001                               | 0.01  | NC <sup>B</sup>    | 0.3                 | 0.7                | 0.2                 | 0.3                | 0.3                 | 1.5                | 0.3                 | 1                  | 0.3                 |
| Lead                      | mg/L  | 0.001                               | 0.025                                       | NC <sup>B</sup>    | 0.12                | 0.08               | NE <sup>A</sup>     | NE <sup>A</sup>    | 0.12                | 0.24               | NE <sup>A</sup>     | 0.08               | NE <sup>A</sup>     |
| Zinc                      | mg/L  | 0.005                               | 0.05  | NC <sup>B</sup>    | 0.7                 | 4                  | 1.32                | 1.78               | 1.94                | 3.08               | 1.68                | 2.76               | 1.86                |
| Total Nitrogen as N       | mg/L  | 0.1                                 | 0.5   | NC <sup>B</sup>    | 3.4                 | 5.8                | 3.6                 | 10.4               | 1.2                 | 8.2                | 0.4                 | 6.4                | 1.2                 |
| Total Phosphorus as P     | mg/L  | 0.01                                | 0.05  | NC <sup>B</sup>    | NE <sup>A</sup>     | 1.2                | 1.6                 | 2.6                | 1                   | 1.4                | NE <sup>A</sup>     | 1                  | NE <sup>A</sup>     |
| Biochemical Oxygen Demand | mg/L  | 2                                   | 2   | NC <sup>B</sup>    | 4                   | 4.5                | 2                   | 2.5                | 1.5                 | 100.5              | NE <sup>A</sup>     | 3.5                | NE <sup>A</sup>     |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.

Table 4.2 Tudar Road Wetland Australian Runoff Quality (ARQ) Enrichment Factors.

| ALS Workgroup Number      |       |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|---------------------------|-------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date               |       |                                     |   | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011          | 8/06/2011           | 28/07/2011         | 28/07/2011          |
| Sampling Site             |       |                                     |   | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) |
|                           | Units | Laboratory Limit of Reporting (LOR) | Australian Runoff Quality Guidelines (2006) |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| Suspended Solids (SS)     | mg/L  | 1                                   | 25  | 0.04               | 0.2                 | 0.24               | NE <sup>A</sup>     | 11.6               | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.08               | 0.04                |
| Cadmium                   | mg/L  | 0.0001                              | 0.0004                                      | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 1                  | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Chromium                  | mg/L  | 0.001                               | 0.01  | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.4                | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                    | mg/L  | 0.001                               | 0.01  | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.1                | NE <sup>A</sup>     | 2.9                | NE <sup>A</sup>     | 0.2                | NE <sup>A</sup>     | 0.2                | 0.2                 |
| Lead                      | mg/L  | 0.001                               | 0.025                                       | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.04               | NE <sup>A</sup>     | 1.76               | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Zinc                      | mg/L  | 0.005                               | 0.05  | 1.76               | NE <sup>A</sup>     | 10.24              | 0.14                | 46.2               | 0.12                | 1.36               | 0.3                 | 0.72               | 0.74                |
| Total Nitrogen as N       | mg/L  | 0.1                                 | 0.5   | 1                  | 1                   | 2.4                | 0.6                 | 22.4               | 0.6                 | 3                  | NE <sup>A</sup>     | 1.6                | 0.4                 |
| Total Phosphorus as P     | mg/L  | 0.01                                | 0.05  | 4.4                | 4.4                 | 1.4                | 0.6                 | 38.8               | 1.6                 | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.4                | 0.4                 |
| Biochemical Oxygen Demand | mg/L  | 2                                   | 2   | 2                  | 2.5                 | 2                  | NE <sup>A</sup>     | 27.5               | 1.5                 | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |

A= Value is below the LOR therefore enrichment factor cannot be established.

Table 4.3 Still Creek Detention Basin Australian Runoff Quality (ARQ) Enrichment Factors.

| ALS Workgroup Number      |       |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|---------------------------|-------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date               |       |                                     |   | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011          | 8/06/2011           | 28/07/2011         | 28/07/2011          |
| Sampling Site             |       |                                     |   | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) |
|                           | Units | Laboratory Limit of Reporting (LOR) | Australian Runoff Quality Guidelines (2006) |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| Suspended Solids (SS)     | mg/L  | 1                                   | 25  | 1.28               | 0.8                 | 0.08               | 0.12                | 0.12               | 0.12                | NE <sup>A</sup>    | 0.4                 | 0.08               | 0.12                |
| Cadmium                   | mg/L  | 0.0001                              | 0.0004                                      | 1.25               | 0.75                | NE <sup>A</sup>    | 0.25                | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Chromium                  | mg/L  | 0.001                               | 0.01  | 0.1                | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 1.8                | NE <sup>A</sup>     |
| Copper                    | mg/L  | 0.001                               | 0.01  | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.2                | 0.2                 | 0.1                | NE <sup>A</sup>     | 0.1                | 0.1                 | 0.4                | 0.3                 |
| Lead                      | mg/L  | 0.001                               | 0.025                                       | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Zinc                      | mg/L  | 0.005                               | 0.05  | 0.16               | 0.12                | 0.56               | 0.22                | 0.3                | 0.2                 | 0.32               | 0.34                | 0.58               | 0.5                 |
| Total Nitrogen as N       | mg/L  | 0.1                                 | 0.5   | 1.4                | 1                   | 1                  | 0.8                 | 1.2                | 1                   | 1.8                | 1                   | 4                  | 2.8                 |
| Total Phosphorus as P     | mg/L  | 0.01                                | 0.05  | 3.2                | 1                   | 0.4                | 2.4                 | 0.4                | 1.2                 | 4.2                | 2.6                 | NE <sup>A</sup>    | 0.2                 |
| Biochemical Oxygen Demand | mg/L  | 2                                   | 2   | 4                  | 7                   | 1.5                | 2                   | 1.5                | 1.5                 | NE <sup>A</sup>    | 1.5                 | NE <sup>A</sup>    | NE <sup>A</sup>     |

A= Value is below the LOR therefore enrichment factor cannot be established.

Table 4.4 Burnum Burnum Detention Basin Australian Runoff Quality (ARQ) Enrichment Factors.

| ALS Workgroup Number      |       |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|---------------------------|-------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date               |       |                                     |   | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011          | 8/06/2011           | 28/07/2011         | 28/07/2011          |
| Sampling Site             |       |                                     |   | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) |
|                           | Units | Laboratory Limit of Reporting (LOR) | Australian Runoff Quality Guidelines (2006) |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| Suspended Solids (SS)     | mg/L  | 1                                   | 25  | 0.2                | 0.96                | 2.68               | 0.32                | NE <sup>A</sup>    | 1.92                | NE <sup>A</sup>    | 0.16                | 0.08               | 0.36                |
| Cadmium                   | mg/L  | 0.0001                              | 0.0004                                      | 0.25               | 0.25                | 4                  | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Chromium                  | mg/L  | 0.001                               | 0.01  | NE <sup>A</sup>    | 0.1                 | 0.3                | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                    | mg/L  | 0.001                               | 0.01  | 0.2                | 0.5                 | 3.3                | 0.2                 | 0.5                | 0.2                 | 0.6                | 0.3                 | 0.7                | 0.3                 |
| Lead                      | mg/L  | 0.001                               | 0.025                                       | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.72               | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Zinc                      | mg/L  | 0.005                               | 0.05  | 0.34               | 0.22                | 6.58               | NE <sup>A</sup>     | 0.32               | 0.12                | 0.36               | 0.24                | 0.46               | 0.2                 |
| Total Nitrogen as N       | mg/L  | 0.1                                 | 0.5   | 2.2                | 2.6                 | 4.8                | 2.2                 | 2                  | 1.6                 | 1.6                | 1.2                 | 0.6                | 2.4                 |
| Total Phosphorus as P     | mg/L  | 0.01                                | 0.05  | 8                  | 3.2                 | 1.6                | 0.4                 | 2.8                | 4.2                 | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | 0.8                 |
| Biochemical Oxygen Demand | mg/L  | 2                                   | 2   | 2.5                | 4                   | 6                  | 2.5                 | NE <sup>A</sup>    | 2                   | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |

A= Value is below the LOR therefore enrichment factor cannot be established.



Table 4.5 Gunnamatta Bay GPT Australian Runoff Quality (ARQ) Enrichment Factors.

| ALS Workgroup Number      |       |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|---------------------------|-------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date               |       |                                     |   | 03/02/2011         | 03/02/2011          | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 08/06/2011         | 08/06/2011          | 28/07/2011         | 28/07/2011          |
| Sampling Site             |       |                                     |   | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) |
|                           | Units | Laboratory Limit of Reporting (LOR) | Australian Runoff Quality Guidelines (2006) |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| Suspended Solids (SS)     | mg/L  | 1                                   | 25  | 0.08               | 0.4                 | 0.16               | 0.16                | NE <sup>A</sup>    | 0.04                | 0.28               | 0.24                | 1.48               | 0.56                |
| Cadmium                   | mg/L  | 0.0001                              | 0.0004                                      | 3.75               | 1.5                 | 3                  | NE <sup>A</sup>     | 0.5                | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Chromium                  | mg/L  | 0.001                               | 0.01  | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | 0.1                 |
| Copper                    | mg/L  | 0.001                               | 0.01  | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.7                | NE <sup>A</sup>     | 0.6                | NE <sup>A</sup>     | 0.6                | 0.6                 | 1.2                | 0.9                 |
| Lead                      | mg/L  | 0.001                               | 0.025                                       | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.16               | NE <sup>A</sup>     | 0.32               | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | 0.08                |
| Zinc                      | mg/L  | 0.005                               | 0.05  | 1.32               | NE <sup>A</sup>     | 0.38               | NE <sup>A</sup>     | 0.48               | NE <sup>A</sup>     | 0.38               | 0.28                | 0.4                | 0.34                |
| Total Nitrogen as N       | mg/L  | 0.1                                 | 0.5   | 0.8                | NE <sup>A</sup>     | 4                  | 1                   | 4.6                | 0.8                 | 3.8                | 1.2                 | 4                  | 2.2                 |
| Total Phosphorus as P     | mg/L  | 0.01                                | 0.05  | 1.6                | 2.4                 | 1                  | NE <sup>A</sup>     | 1.4                | NE <sup>A</sup>     | 0.8                | 0.2                 | 1.2                | 1.2                 |
| Biochemical Oxygen Demand | mg/L  | 2                                   | 2   | 3.5                | 3                   | 2                  | 1.5                 | 1.5                | NE <sup>A</sup>     | NE <sup>A</sup>    | 1.5                 | 1.5                | NE <sup>A</sup>     |

A= Value is below the LOR therefore enrichment factor cannot be established.

Table 4.6 Cronulla Beach GPT Australian Runoff Quality (ARQ) Enrichment Factors.

| ALS Workgroup Number      |       |                                     |   | EW1100422         | EW1100422          | ES1107703         | ES1107703          | ES1109140         | ES1109140          | EW1101805         | EW1101805          | EW1102223         | EW1102223          |
|---------------------------|-------|-------------------------------------|---|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|
| Sample Date               |       |                                     |   | 03/02/2011        | 03/02/2011         | 13/04/2011        | 13/04/2011         | 11/05/2011        | 11/05/2011         | 08/06/2011        | 08/06/2011         | 28/07/2011        | 28/07/2011         |
| Sampling Site             |       |                                     |   | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) |
|                           | Units | Laboratory Limit of Reporting (LOR) | Australian Runoff Quality Guidelines (2006) |                   |                    |                   |                    |                   |                    |                   |                    |                   |                    |
| Suspended Solids (SS)     | mg/L  | 1                                   | 25  | 0.32              | NC <sup>B</sup>    | 0.36              | 0.28               | 0.24              | 0.6                | 0.2               | 0.2                | 0.64              | 0.32               |
| Cadmium                   | mg/L  | 0.0001                              | 0.0004                                      | 0.5               | NC <sup>B</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    |
| Chromium                  | mg/L  | 0.001                               | 0.01  | 0.1               | NC <sup>B</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | 0.1               | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | 0.2               | 0.3                |
| Copper                    | mg/L  | 0.001                               | 0.01  | 1.2               | NC <sup>B</sup>    | 1.3               | NE <sup>A</sup>    | 0.6               | NE <sup>A</sup>    | 0.5               | 0.5                | 4.2               | 2.7                |
| Lead                      | mg/L  | 0.001                               | 0.025                                       | NE <sup>A</sup>   | NC <sup>B</sup>    | 0.28              | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | 0.16              | 0.08               |
| Zinc                      | mg/L  | 0.005                               | 0.05  | 0.48              | NC <sup>B</sup>    | 0.84              | NE <sup>A</sup>    | 0.22              | NE <sup>A</sup>    | 0.4               | 0.34               | 1.46              | 0.84               |
| Total Nitrogen as N       | mg/L  | 0.1                                 | 0.5   | 9.2               | NC <sup>B</sup>    | 9.2               | 2.4                | 8.4               | 0.2                | 9.4               | 5.2                | 3                 | 1.6                |
| Total Phosphorus as P     | mg/L  | 0.01                                | 0.05  | 13.6              | NC <sup>B</sup>    | 5.4               | 0.8                | 5                 | NE <sup>A</sup>    | 3.4               | 1.6                | 10.2              | 5                  |
| Biochemical Oxygen Demand | mg/L  | 2                                   | 2   | 5.5               | NC <sup>B</sup>    | 7.5               | 2                  | 4                 | 1.5                | 2                 | 1.5                | 5                 | 3                  |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.

Table 4.7 Mianga Avenue Wetland Control Site (CS) Enrichment Factors.

| ALS Workgroup Number         |           |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|------------------------------|-----------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date                  |           |                                     |   | 03/02/2011         | 03/02/2011          | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 08/06/2011         | 08/06/2011          | 28/07/2011         | 28/07/2011          |
| Sampling Site                |           |                                     |   | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) | Point 22A (Inflow) | Point 22B (Outflow) |
|                              | Units     | Laboratory Limit of Reporting (LOR) | Port Hacking River Catchment Control Site Kangaroo Creek <sup>C</sup> |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| pH                           | pH Unit   | 0.1                                 | 7.5   | NC <sup>B</sup>    | 0.97                | 0.97               | 0.99                | 0.91               | 0.96                | 0.99               | 0.97                | 1.04               | 1.01                |
| Electrical Conductivity (NC) | µS/cm     | 1                                   | 240   | NC <sup>B</sup>    | 0.58                | 1.20               | 0.33                | 1.31               | 0.48                | 1.76               | 0.53                | 1.63               | 0.65                |
| Dissolved Oxygen             | mg/L      | 0.01                                | 5.8   | NC <sup>B</sup>    | 1.51                | 0.68               | 1.31                | 1.95               | 1.23                | 1.91               | 1.64                | 2.02               | 1.90                |
| Suspended Solids (SS)        | mg/L      | 1                                   | 2   | NC <sup>B</sup>    | 7.5                 | 2.5                | 9.5                 | 9                  | 5                   | 5                  | NE <sup>A</sup>     | 3                  | 1                   |
| Arsenic                      | mg/L      | 0.001                               | 0.0005  | NC <sup>B</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                       | mg/L      | 0.001                               | 0.0005  | NC <sup>B</sup>    | 6                   | 14                 | 4                   | 6                  | 6                   | 30                 | 6                   | 20                 | 6                   |
| Lead                         | mg/L      | 0.001                               | 0.0005  | NC <sup>B</sup>    | 6                   | 4                  | NE <sup>A</sup>     | NE <sup>A</sup>    | 6                   | 12                 | NE <sup>A</sup>     | 4                  | NE <sup>A</sup>     |
| Zinc                         | mg/L      | 0.005                               | 0.005   | NC <sup>B</sup>    | 7                   | 40                 | 13.2                | 17.8               | 19.4                | 30.8               | 16.8                | 27.6               | 18.6                |
| Ammonia as N                 | mg/L      | 0.01                                | 0.005   | NC <sup>B</sup>    | 46                  | 18                 | NE <sup>A</sup>     | 6                  | 12                  | 14                 | 12                  | 10                 | 24                  |
| Total Nitrogen as N          | mg/L      | 0.1                                 | 0.2   | NC <sup>B</sup>    | 8.5                 | 14.5               | 9                   | 26                 | 3                   | 20.5               | 1                   | 16                 | 3                   |
| Total Phosphorus as P        | mg/L      | 0.01                                | 0.005   | NC <sup>B</sup>    | NE <sup>A</sup>     | 12                 | 16                  | 26                 | 10                  | 14                 | NE <sup>A</sup>     | 10                 | NE <sup>A</sup>     |
| Biochemical Oxygen Demand    | mg/L      | 2                                   | 1   | NC <sup>B</sup>    | 8                   | 9                  | 4                   | 5                  | 3                   | 201                | NE <sup>A</sup>     | 7                  | NE <sup>A</sup>     |
| Enterococci                  | CFU/100mL | 1                                   | 10  | NC <sup>B</sup>    | 18                  | 600                | 2.6                 | 8.2                | 0.6                 | 140                | 0.5                 | 14                 | 2.2                 |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.

C= Guidelines are mode values determined from data taken over a period from 1994-2010.

Table 4.8 Tudar Road Wetland Control Site (CS) Enrichment Factors.

| ALS Workgroup Number         |           |                                     |  | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|------------------------------|-----------|-------------------------------------|--|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date                  |           |                                     |  | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011          | 8/06/2011           | 28/07/2011         | 28/07/2011          |
| Sampling Site                |           |                                     |  | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) | Point 38A (Inflow) | Point 38B (Outflow) |
|                              | Units     | Laboratory Limit of Reporting (LOR) | Georges River Catchment Control Site Woronora River <sup>B</sup> |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| pH                           | pH Unit   | 0.1                                 | 7.2  | 0.99               | 0.90                | 0.94               | 0.92                | 0.875              | 0.96                | 1.03               | 0.96                | 1.03               | 0.97                |
| Electrical Conductivity (NC) | µS/cm     | 1                                   | 190  | 2.42               | 1.63                | 1.86               | 1.4                 | 2.65               | 2.25                | 2.49               | 2.16                | 2.21               | 2.12                |
| Dissolved Oxygen             | mg/L      | 0.01                                | 11.1   | 0.64               | 0.28                | 0.46               | 0.31                | 0.66               | 0.37                | 0.90               | 0.44                | 0.92               | 0.56                |
| Temperature                  | °C        | 0.1                                 | 9.9  | 2.93               | 2.64                | 2.09               | 1.55                | 1.59               | 1.26                | 1.45               | 1.09                | 1.47               | 1.23                |
| Suspended Solids (SS)        | mg/L      | 1                                   | 2  | 0.5                | 2.5                 | 3                  | NE <sup>A</sup>     | 145                | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 1                  | 0.5                 |
| Arsenic                      | mg/L      | 0.001                               | 0.001  | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 2                  | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                       | mg/L      | 0.001                               | 0.05   | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.02               | NE <sup>A</sup>     | 0.58               | NE <sup>A</sup>     | 0.04               | NE <sup>A</sup>     | 0.04               | 0.04                |
| Lead                         | mg/L      | 0.001                               | 0.0005   | NE <sup>A</sup>    | NE <sup>A</sup>     | 2                  | NE <sup>A</sup>     | 88                 | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Zinc                         | mg/L      | 0.005                               | 0.005  | 17.6               | NE <sup>A</sup>     | 102.4              | 1.4                 | 462                | 1.2                 | 13.6               | 3                   | 7.2                | 7.4                 |
| Ammonia as N                 | mg/L      | 0.01                                | 0.005  | 22                 | 4                   | NE <sup>A</sup>    | NE <sup>A</sup>     | 182                | 6                   | 10                 | 4                   | 4                  | 4                   |
| Total Kjeldahl Nitrogen as N | mg/L      | 0.1                                 | 0.005  | 100                | 100                 | 180                | 60                  | NE <sup>A</sup>    | NE <sup>A</sup>     | 100                | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Total Nitrogen as N          | mg/L      | 0.1                                 | 0.005  | 100                | 100                 | 240                | 60                  | 2240               | 60                  | 300                | NE <sup>A</sup>     | 160                | 40                  |
| Total Phosphorus as P        | mg/L      | 0.01                                | 0.05   | 4.4                | 4.4                 | 1.4                | 0.6                 | 38.8               | 1.6                 | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.4                | 0.4                 |
| Biochemical Oxygen Demand    | mg/L      | 2                                   | 1  | 4                  | 5                   | 4                  | NE <sup>A</sup>     | 55                 | 3                   | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Enterococci                  | CFU/100mL | 1                                   | 10   | 72                 | 18                  | 27                 | 3.4                 | 4500               | 1                   | 41                 | 0.6                 | 20                 | 1.6                 |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.



Table 4.9 Still Creek Detention Basin Control Site (CS) Enrichment Factors.

| ALS Workgroup Number         |           |                                     |  | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|------------------------------|-----------|-------------------------------------|--|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date                  |           |                                     |  | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011          | 8/06/2011           | 28/07/2011         | 28/07/2011          |
| Sampling Site                |           |                                     |  | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) | Point 25A (Inflow) | Point 25B (Outflow) |
|                              | Units     | Laboratory Limit of Reporting (LOR) | Georges River Catchment Control Site Woronora River <sup>B</sup> |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| pH                           | pH Unit   | 0.1                                 | 7.2  | 1.07               | 0.99                | 1.03               | 0.97                | 0.93               | 0.93                | 1.08               | 1.03                | 1.08               | 1.03                |
| Electrical Conductivity (NC) | µS/cm     | 1                                   | 190  | 2.63               | 2.11                | 2.04               | 0.78                | 1.82               | 2.21                | 2.61               | 2.75                | 4.33               | 3.44                |
| Dissolved Oxygen             | mg/L      | 0.01                                | 11.1   | 0.87               | 0.75                | 0.83               | 0.45                | 0.98               | 0.67                | 1.02               | 0.57                | 0.89               | 0.68                |
| Temperature                  | °C        | 0.1                                 | 9.9  | 2.90               | 3.04                | 1.82               | 1.79                | 1.30               | 1.25                | 1.15               | 0.91                | 1.16               | 1.20                |
| Suspended Solids (SS)        | mg/L      | 1                                   | 2  | 16                 | 10                  | 1                  | 1.5                 | 1.5                | 1.5                 | NE <sup>A</sup>    | 5                   | 1                  | 1.5                 |
| Arsenic                      | mg/L      | 0.001                               | 0.001  | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                       | mg/L      | 0.001                               | 0.05   | NE <sup>A</sup>    | NE <sup>A</sup>     | 0.04               | 0.04                | 0.02               | NE <sup>A</sup>     | 0.02               | 0.02                | 0.08               | 0.06                |
| Lead                         | mg/L      | 0.001                               | 0.0005   | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Zinc                         | mg/L      | 0.005                               | 0.005  | 1.6                | 1.2                 | 5.6                | 2.2                 | 3                  | 2                   | 3.2                | 3.4                 | 5.8                | 5                   |
| Ammonia as N                 | mg/L      | 0.01                                | 0.005  | 12                 | 8                   | NE <sup>A</sup>    | 6                   | 6                  | 8                   | 8                  | 10                  | 6                  | 20                  |
| Total Kjeldahl Nitrogen as N | mg/L      | 0.1                                 | 0.005  | 140                | 100                 | 80                 | 80                  | NE <sup>A</sup>    | NE <sup>A</sup>     | 60                 | 80                  | NE <sup>A</sup>    | 80                  |
| Total Nitrogen as N          | mg/L      | 0.1                                 | 0.005  | 140                | 100                 | 100                | 80                  | 120                | 100                 | 180                | 100                 | 400                | 280                 |
| Total Phosphorus as P        | mg/L      | 0.01                                | 0.05   | 3.2                | 1                   | 0.4                | 2.4                 | 0.4                | 1.2                 | 4.2                | 2.6                 | NE <sup>A</sup>    | 0.2                 |
| Biochemical Oxygen Demand    | mg/L      | 2                                   | 1  | 8                  | 14                  | 3                  | 4                   | 3                  | 3                   | NE <sup>A</sup>    | 3                   | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Enterococci                  | CFU/100mL | 1                                   | 10   | 8                  | 63                  | 19                 | 590                 | 3.8                | 100                 | 3.8                | 12                  | 28                 | 62                  |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.

Table 4.10 Burnum Burnum Detention Basin Control Site (CS) Enrichment Factors.

| ALS Workgroup Number         |           |                                     |  | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|------------------------------|-----------|-------------------------------------|--|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date                  |           |                                     |  | 3/02/2011          | 3/02/2011           | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 8/06/2011          | 8/06/2011           | 28/07/2011         | 28/07/2011          |
| Sampling Site                |           |                                     |  | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) | Point 42A (Inflow) | Point 42B (Outflow) |
|                              | Units     | Laboratory Limit of Reporting (LOR) | Georges River Catchment Control Site Woronora River <sup>B</sup> |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| pH                           | pH Unit   | 0.1                                 | 7.2  | 0.99               | 1.10                | 0.99               | 1                   | 1.08               | 1.14                | 1.10               | 1.06                | 1.11               | 1.01                |
| Electrical Conductivity (NC) | µS/cm     | 1                                   | 190  | 2.79               | 138.42              | 2.93               | 36.05               | 3.59               | 3.02                | 4.04               | 21.84               | 3.73               | 10.84               |
| Dissolved Oxygen             | mg/L      | 0.01                                | 11.1   | 0.19               | 0.79                | 0.33               | 0.56                | 0.63               | 0.81                | 0.75               | 0.88                | 0.77               | 0.80                |
| Temperature                  | °C        | 0.1                                 | 9.9  | 2.49               | 3.04                | 2.53               | 2.53                | 1.47               | 1.17                | 1.33               | 1.08                | 1.35               | 1.15                |
| Suspended Solids (SS)        | mg/L      | 1                                   | 2  | 2.5                | 12                  | 33.5               | 4                   | NE <sup>A</sup>    | 24                  | NE <sup>A</sup>    | 2                   | 1                  | 4.5                 |
| Arsenic                      | mg/L      | 0.001                               | 0.001  | NE <sup>A</sup>    | 8                   | 2                  | NE <sup>A</sup>     | NE <sup>A</sup>    | 1                   | 2                  | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                       | mg/L      | 0.001                               | 0.05   | 0.04               | 0.1                 | 0.66               | 0.04                | 0.1                | 0.04                | 0.12               | 0.06                | 0.14               | 0.06                |
| Lead                         | mg/L      | 0.001                               | 0.0005   | NE <sup>A</sup>    | NE <sup>A</sup>     | 36                 | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Zinc                         | mg/L      | 0.005                               | 0.005  | 3.4                | 2.2                 | 65.8               | NE <sup>A</sup>     | 3.2                | 1.2                 | 3.6                | 2.4                 | 4.6                | 2                   |
| Ammonia as N                 | mg/L      | 0.01                                | 0.005  | 60                 | NE <sup>A</sup>     | 200                | 6                   | 10                 | 20                  | 8                  | 28                  | 12                 | 30                  |
| Total Kjeldahl Nitrogen as N | mg/L      | 0.1                                 | 0.005  | 200                | 260                 | 440                | 220                 | NE <sup>A</sup>    | NE <sup>A</sup>     | 80                 | 100                 | NE <sup>A</sup>    | 200                 |
| Total Nitrogen as N          | mg/L      | 0.1                                 | 0.005  | 220                | 260                 | 480                | 220                 | 200                | 160                 | 160                | 120                 | 60                 | 240                 |
| Total Phosphorus as P        | mg/L      | 0.01                                | 0.05   | 8                  | 3.2                 | 1.6                | 0.4                 | 2.8                | 4.2                 | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | 0.8                 |
| Biochemical Oxygen Demand    | mg/L      | 2                                   | 1  | 5                  | 8                   | 12                 | 5                   | NE <sup>A</sup>    | 4                   | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Enterococci                  | CFU/100mL | 1                                   | 10   | 62                 | 5.6                 | 860                | 2.4                 | 1.6                | 1                   | 2                  | 2                   | 6.2                | 3.6                 |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.

Table 4.11 Gunnamatta Bay GPT Control Site (CS) Enrichment Factors.

| ALS Workgroup Number         |           |                                     |   | EW1100422          | EW1100422           | ES1107703          | ES1107703           | ES1109140          | ES1109140           | EW1101805          | EW1101805           | EW1102223          | EW1102223           |
|------------------------------|-----------|-------------------------------------|---|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| Sample Date                  |           |                                     |   | 03/02/2011         | 03/02/2011          | 13/04/2011         | 13/04/2011          | 11/05/2011         | 11/05/2011          | 08/06/2011         | 08/06/2011          | 28/07/2011         | 28/07/2011          |
| Sampling Site                |           |                                     |   | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) | Point 11A (Inflow) | Point 11B (Outflow) |
|                              | Units     | Laboratory Limit of Reporting (LOR) | Port Hacking River Catchment Control Site Kangaroo Creek <sup>B</sup> |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |
| pH                           | pH Unit   | 0.1                                 | 7.5   | 1.03               | 1.04                | 1.05               | 1.08                | 0.96               | 1.05                | 1.05               | 1.07                | 1.05               | 1.05                |
| Electrical Conductivity (NC) | µS/cm     | 1                                   | 240   | 151.67             | 142.5               | 1.43               | 6.83                | 117.08             | 190                 | 51.67              | 142.92              | 18.83              | 46.67               |
| Dissolved Oxygen             | mg/L      | 0.01                                | 5.8   | 1.42               | 1.16                | 1.1                | 1.25                | 1.69               | 1.27                | 1.79               | 1.69                | 1.66               | 1.61                |
| Suspended Solids (SS)        | mg/L      | 1                                   | 2   | 1.00               | 5                   | 2                  | 2                   | NE <sup>A</sup>    | 0.5                 | 3.5                | 3                   | 18.5               | 7                   |
| Arsenic                      | mg/L      | 0.001                               | 0.0005  | 18.00              | 24                  | NE <sup>A</sup>    | NE <sup>A</sup>     | 4                  | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     |
| Copper                       | mg/L      | 0.001                               | 0.0005  | NE <sup>A</sup>    | NE <sup>A</sup>     | 14                 | NE <sup>A</sup>     | 12                 | NE <sup>A</sup>     | 12                 | 12                  | 24                 | 18                  |
| Lead                         | mg/L      | 0.001                               | 0.0005  | NE <sup>A</sup>    | NE <sup>A</sup>     | 8                  | NE <sup>A</sup>     | 16                 | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | 4                   |
| Zinc                         | mg/L      | 0.005                               | 0.005   | 13.20              | NE <sup>A</sup>     | 3.8                | NE <sup>A</sup>     | 4.8                | NE <sup>A</sup>     | 3.8                | 2.8                 | 4                  | 3.4                 |
| Ammonia as N                 | mg/L      | 0.01                                | 0.005   | NE <sup>A</sup>    | NE <sup>A</sup>     | 24                 | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | NE <sup>A</sup>    | NE <sup>A</sup>     | 26                 | 22                  |
| Total Nitrogen as N          | mg/L      | 0.1                                 | 0.2   | 2.00               | NE <sup>A</sup>     | 10                 | 2.5                 | 11.5               | 2                   | 9.5                | 3                   | 10                 | 5.5                 |
| Total Phosphorus as P        | mg/L      | 0.01                                | 0.005   | 16.00              | 24                  | 10                 | NE <sup>A</sup>     | 14                 | NE <sup>A</sup>     | 8                  | 2                   | 12                 | 12                  |
| Biochemical Oxygen Demand    | mg/L      | 2                                   | 1   | 7.00               | 6                   | 4                  | 3                   | 3                  | NE <sup>A</sup>     | NE <sup>A</sup>    | 3                   | 3                  | NE <sup>A</sup>     |
| Enterococci                  | CFU/100mL | 1                                   | 10  | 33.00              | 9                   | 160                | 64                  | 1200               | 130                 | 56                 | 26                  | 130                | 80                  |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.



Table 4.12 Cronulla Beach GPT Control Site (CS) Enrichment Factors.

| ALS Workgroup Number         |           |                                     |   | EW1100422         | EW1100422          | ES1107703         | ES1107703          | ES1109140         | ES1109140          | EW1101805         | EW1101805          | EW1102223         | EW1102223          |
|------------------------------|-----------|-------------------------------------|---|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|
| Sample Date                  |           |                                     |   | 03/02/2011        | 03/02/2011         | 13/04/2011        | 13/04/2011         | 11/05/2011        | 11/05/2011         | 08/06/2011        | 08/06/2011         | 28/07/2011        | 28/07/2011         |
| Sampling Site                |           |                                     |   | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) | Point 9A (Inflow) | Point 9B (Outflow) |
|                              | Units     | Laboratory Limit of Reporting (LOR) | Port Hacking River Catchment Control Site Kangaroo Creek <sup>C</sup> |                   |                    |                   |                    |                   |                    |                   |                    |                   |                    |
| pH                           | pH Unit   | 0.1                                 | 7.5   | 1.01              | NC <sup>B</sup>    | 0.96              | 1.13               | 1.09              | 1.07               | 1                 | 1.04               | 1.08              | 1.01               |
| Electrical Conductivity (NC) | µS/cm     | 1                                   | 240   | 5.54              | NC <sup>B</sup>    | 3.23              | 66.25              | 2.57              | 198.33             | 3.89              | 36.92              | 50.83             | 5.42               |
| Dissolved Oxygen             | mg/L      | 0.01                                | 5.8   | 1.07              | NC <sup>B</sup>    | 0.89              | 1.48               | 1.52              | 1.45               | 1.56              | 1.88               | 1.79              | 1.59               |
| Suspended Solids (SS)        | mg/L      | 1                                   | 2   | 4                 | NC <sup>B</sup>    | 4.5               | 3.5                | 3                 | 7.5                | 2.5               | 2.50               | 8                 | 4                  |
| Arsenic                      | mg/L      | 0.001                               | 0.0005  | 4                 | NC <sup>B</sup>    | 2                 | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    |
| Copper                       | mg/L      | 0.001                               | 0.0005  | 24                | NC <sup>B</sup>    | 26                | NE <sup>A</sup>    | 12                | NE <sup>A</sup>    | 10                | 10                 | 84                | 54                 |
| Lead                         | mg/L      | 0.001                               | 0.0005  | NE <sup>A</sup>   | NC <sup>B</sup>    | 14                | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | NE <sup>A</sup>   | NE <sup>A</sup>    | 8                 | 4                  |
| Zinc                         | mg/L      | 0.005                               | 0.005   | 4.8               | NC <sup>B</sup>    | 8.4               | NE <sup>A</sup>    | 2.2               | NE <sup>A</sup>    | 4                 | 3.4                | 14.6              | 8.4                |
| Ammonia as N                 | mg/L      | 0.01                                | 0.005   | 258               | NC <sup>B</sup>    | 126               | NE <sup>A</sup>    | 76                | NE <sup>A</sup>    | 52                | NE <sup>A</sup>    | 48                | NE <sup>A</sup>    |
| Total Nitrogen as N          | mg/L      | 0.1                                 | 0.2   | 23                | NC <sup>B</sup>    | 23                | 6                  | 21                | 0.5                | 23.5              | 13                 | 7.5               | 4                  |
| Total Phosphorus as P        | mg/L      | 0.01                                | 0.005   | 136               | NC <sup>B</sup>    | 54                | 8                  | 50                | NE <sup>A</sup>    | 34                | 16                 | 102               | 50                 |
| Biochemical Oxygen Demand    | mg/L      | 2                                   | 1   | 11                | NC <sup>B</sup>    | 15                | 4                  | 8                 | 3                  | 4                 | 3                  | 10                | 6                  |
| Enterococci                  | CFU/100mL | 1                                   | 10  | 200               | NC <sup>B</sup>    | 400               | 71                 | 220               | 3.4                | 350               | 23                 | 31                | 20                 |

A= Value is below the LOR therefore enrichment factor cannot be established.

B= Sample wasn't collected so no data was available to determine the enrichment factor.

C= Guidelines are mode values determined from data taken over a period from 1994-2010.

#### **4.4 Most Important Water Quality Indicator**

Although the vast majority of studies examining stormwater employ a range of parameters in the assessment of the overall health of the system, it is possible to recognise individual contaminants as being the more important indicators of water quality at a given location. The results for Tudar Road Wetland for example, could largely be demonstrated by simply measuring suspended solids, which in this instance was the main driver for the changes in nearly all of the other constituents examined. It is possible the same approach could be adopted for Burnum Burnum Detention Basin with suspended solids apparently driving changes in a number of the other parameters measured. In the case of Mianga Avenue Wetland, total nitrogen would represent the most important parameter with this measure giving a good indication of the behaviour of nutrients in the system, including total phosphorus. This could also be true of Gunnamatta Bay GPT, Still Creek Detention Basin and Cronulla Beach GPT where nutrients are perhaps the best parameter to use as an indicator of overall water quality due to the lack of any relationship between suspended solids and the other constituents. Simply measuring a field parameter such as pH or a single metal significantly limits the assessment of the stormwater quality and as a result nutrient analysis is probably the best selection as this can give some indication of ammonia, nitrite and nitrate, total nitrogen and total phosphorus behaviour in the system. While in some instances the selection of a single water quality parameter can provide a reasonable insight into the behaviour of other constituents and, therefore, overall water quality, this is not always the case. It is therefore always in the best interests of the study to select and measure a range of contaminants in order to achieve the most accurate assessment. Indeed, the relationship observed at Tudar Road Wetland would not have become apparent without such an approach and the importance of suspended solids, in that location, would not have been recognised as a result.

#### **4.5 Presentation of Human and Ecological Health Impacts to the Community**

While the data collected for each of the SQIDs provides an important insight into their functioning, which is of use to Council, another very important aspect of the process is the presentation of this information to the community. Communication of the human and ecological health impacts of the inflow and the outflow water can provide the community with an understanding of the water quality around where they live and work and how that may impact them or their families. It can also help them to understand how they may be

contributing to the problem. In order to do this effectively it is necessary to design a clear and easily understandable communication medium. One possibility is the categorisation of the water quality results for the sites studied. This could involve scoring the inflow and outflow data using a scale from A to D with the terms Excellent, Good, Fair and Poor to describe the score given. Scores could be assigned to describe a variety of water quality parameters including metals, nutrients and bacteria and an overall score could be given for the site as a whole. One method of deciding what score to assign could be to employ enrichment tables, as seen above. This involves comparing the results for the various parameters with the established guidelines. Depending upon the spread of results received, the enrichment factor values could be divided to achieve four categories, as above. This represents an effective means of translating the quantitative data into a qualitative form. Such an approach would allow the audience to quickly and easily understand the water quality at a given site. This information could then be presented on a pamphlet or postcard size printout which could be distributed amongst the community, either through letter box drops, which would probably be the most effective, or at community information events. Community information sessions could also assist with the communication of the water quality information. At such an event the categorisation approach could be explained in more detail, including how the system was devised. Community members would have the opportunity to ask questions which could be answered in more detail, if required, by a relevant Council employee or external professional. In this sense these two approaches would operate effectively in unison to provide the community with the information they need in a format they can understand. Therefore this would represent the most effective means of presenting such data to the community.

#### **4.6 Water Quality and Environmental Management Implications**

Overall, the water quality data suggests that stormwater within the Sutherland Shire is of a reasonable quality and has improved since 1994, particularly in the sense of heavy metal concentrations which are, in most instances, quite low. Indeed, oil and grease measurements are no longer taken as it was found that over time the values were at such a consistently low level that it was not considered necessary to examine this constituent any longer. Some nutrient contamination can be observed across all sites, although this is expected, given the prevalence of sources for such pollution within an urban catchment. With proper management the potential impact on human and ecological health can be controlled. The aerial photos and zoning maps illustrate that catchment land use has changed little since 2000/2001, which



suggests that any changes in pollutant concentrations can be attributed to behavioural and process changes within the catchments. Of comfort is the fact that the data appears to justify the collection of inflow and outflow data on the same sampling day. It is possible under such circumstances, that a time-lag could exist between the two points and therefore sampling one straight after the other does not provide an accurate indication of the relative water quality. The data collected does not show evidence of a time-lag, rather both the inflow and outflow appear to follow the same trend, which supports the current sampling practices.

The comparisons of the different sites demonstrate that those devices which have been designed specifically for stormwater treatment are the most effective with Tudar Road Wetland functioning the best, despite the need to harvest the reeds growing in the wetland. As discussed above Mianga Avenue Wetland appears to be operating relatively well though it is interesting when this site is compared with Cronulla Beach GPT. Cronulla Beach GPT appears to provide a relatively adequate treatment of nutrients despite the absence of a vegetated wetland basin, beneficial to nutrient removal. Similar results were observed at Gunnamatta Bay GPT which suggests that, despite the absence of a wetland system, a reasonable degree of nutrient removal can occur. It is possible the nutrient load is being incorporated into the sediment within the GPT and as a result, being retained within the system. It is therefore difficult to unequivocally recommend one kind of installation over the other. It is clear however, that sites such as Burnum Burnum Detention Basin and Still Creek Detention Basin are poorly functioning which could be resulting in unnecessarily polluted outflows, to Woronora River for example. Furthermore, poorly functioning devices can contribute to the degradation in aesthetic appeal of a location, which is particularly so for Still Creek Detention Basin where the channel is overgrown by weeds and the basin holds essentially, stagnant water. In these instances, the opportunity exists to improve the sites and upgrade their stormwater treatment potential as well as improve the amenity of the area. Council is currently engaged in preparing a plan of management for these sites in order to understand how best to remedy the problems encountered. Once this process, which includes community consultation, has been completed then work can be undertaken to redesign and improve these installations.

## 5. Conclusions and Recommendations

This study shows that it is difficult to clearly define what represents a superior stormwater quality improvement device under some circumstances, though it is evident that specifically designing the system for stormwater quality control is necessary. Attempts made to utilise sites, originally intended for other purposes and possibly poorly designed in the first instance, do not achieve the required outcome and are likely to be plagued by operational problems. The results show that those specifically designed devices are indeed improving the quality of stormwater outflow and while not all discharges meet the guideline values they are, in the majority of cases, an improvement upon the inflow quality. In order to investigate further the causes of any breaches of guideline values, as well as the operational efficiency of the SQIDs in the Sutherland Shire, a number of recommendations for future studies have been provided. Firstly, an examination of the constituent metal content of the sediment at the inflow and outflow of each site would provide a more accurate representation of the kinds of heavy metal loads originating from the catchment and the SQIDs potential for controlling this. Secondly, expand the number of sites with the inclusion of an equal number of wetland systems and gross pollutant trap systems to investigate the relative treatment potential of these two designs further. This could reveal which of these systems is the most effective. It would also be worthwhile to conduct a more detailed study of the impact rainfall has upon the operation of the devices. This could involve sampling for a number of days after the rain event and if possible before the event to more accurately determine how rainfall influences the pollutant concentrations. Finally, a detailed review of the catchment area of an individual device or devices could be performed with a view to identifying the sources of contaminants measured in the SQID. Such a study could have wider implications for land use management and could guide decisions affecting the installation of SQIDs and development approvals around water ways. Ultimately, this would allow Sutherland Shire Council to improve, what appears to be, an already comprehensive stormwater management system.

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## **Appendix 1: Legend Description for Geology Maps**

- Qhf- “Marine” quartz sand, fine to medium, shelly. Leached to varying degrees.
- Qhbr- “Marine” quartz sand, minor shell content, interdune (swale) silt and fine sand.
- Qal- Quartz and lithic “fluvial” sand, silt and clay.
- Qhb- “Marine” quartz sand, medium to coarse, with shelly fragments.
- Rh- Hawkesbury Sandstone; medium to coarse-grained quartz sandstone, very minor shale and laminate lenses.
- Rhs- Claystone, siltstone and laminate (“shale lenses”).
- mf- Man-made fill. Dredged estuarine sand and mud, coal washing, industrial and household waste.
- water- Water surface such as a lake, river or stream.

## **Appendix 2: Legend Description for Past Zoning SSLEP 2000 Maps**

- 1 (a)- Rural
- 1 (b)- Rural (Future Urban)
- 2 (a1)- Residential
- 2 (a2)- Residential
- 2 (b)- Residential
- 2 (c)- Residential
- 2 (e1)- Residential
- 2 (e2)- Residential
- 3 (a)- General Business
- 3 (b)- Neighbourhood Business
- 4 (a)- General Industrial
- 5 (a)- Special Uses
- 5 (b)- Special Uses (Railways)
- 5 (c)- Special Uses (Arterial Road)
- 5 (d)- Special Uses (Future Arterial Road)
- 5 (e)- Special Uses (Proposed Road)
- 5 (f)- Special Uses (Waste Recycling)
- 5 (g)- Special Uses (General Road)
- 6 (a)- Public Recreation
- 6 (b)- Private Recreation
- 6 (c)- Regional Recreation
- 6 (d)- Future Recreation
- 7 (a)- Environmental Protection (Waterways)
- 7 (b)- Environmental Protection (Bushland)
- 7 (c)- Environmental Protection (Water Catchment)
- 8 (a)- National Parks, Nature Reserves and State Recreation Areas
- 9 (a)- Mixed Residential/Business

### **Appendix 3: Legend Description for Current Zoning SSLEP 2006 Maps**

|          |  |
|----------|--|
| Zone 1-  | Environmental Housing (Environmentally Sensitive Land)       |
| Zone 2-  | Environmental Housing (Scenic Quality)                       |
| Zone 3-  | Environmental Housing (Bushland)                             |
| Zone 4-  | Local Housing  |
| Zone 5-  | Multiple Dwelling A  |
| Zone 6-  | Multiple Dwelling B  |
| Zone 7-  | Mixed Use—Kirrawee   |
| Zone 8-  | Urban Centre   |
| Zone 9-  | Local Centre   |
| Zone 10- | Neighbourhood Centre   |
| Zone 11- | Employment   |
| Zone 12- | Special Uses   |
| Zone 13- | Public Open Space  |
| Zone 14- | Public Open Space (Bushland)                                 |
| Zone 15- | Private Recreation   |
| Zone 16- | Environmental Protection (Waterways)                         |
| Zone 17- | Environmental Protection (Low Impact Rural)                  |
| Zone 18- | Environmental Protection (Water Catchment)                   |
| Zone 19- | Aquatic Reserves   |
| Zone 20- | National Parks, Nature Reserves and State Conservation Areas |
| Zone 21- | Railway  |
| Zone 22- | Arterial Road  |
| Zone 23- | Road   |
| Zone 24- | Transport Reservation  |